SCIENTIFIC DIALOGUES.

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SCIENTIFIC DIALOGUES·

INTENDED FOR THE

INSTRUCTION AND ENTERTAINMENT

OF

YOUNG PEOPLE:

IN WHICH THE FIRST PRINCIPLES OF NATURAL AND EXPERIMENTAL PHILOSOPHY ARE FULLY EXPLAINED.

BY THE

REV. JEREMIAH JOYCE,

WITH

CORRECTIONS AND IMPROVEMENTS BY DR. OLINTHUS GREGORY.

A NEW AND ENLARGED EDITION,

CONTAINING THE RECENT ADDITIONS TO SCIENCE.

BY CHARLES V. WALKER, ESQ.,

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Author of
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1853.

" Conversation, with the habit of explaining the meaning of words, and the structure of common domestic implements, to children, is the sure and effectual means of preparing the mind for the acquirement of science."

EDGEWORTH's *Practical Education.*

PREFACE

TO

THE NEW EDITION.

In preparing an Edition of these Dialogues, which should contain some of the recent acquisitions to science, I have been careful to adhere strictly to the spirit of the Author; and also not to confuse the young reader, for whose use alone the book is written, with matter too abstruse for his comprehension. I have made very few inroads upon the original text; where I have felt it necessary to erase any passage, I have substituted the modern interpretation. My pen at times has been yearning to run on and enter more fully into detail on subjects, upon which I have been compelled barely to touch. In presenting to my young friends this edition of "Joyce's Scientific Dialogues" in its integrity, I hope they will derive as much pleasure and instruction from it as I myself remember to have derived in my boyish days.

CHARLES V. WALKER.

September, 1846.

PREFACE

TO

THE NEW AND ENLARGED EDITION.

Considerable alteration has been made in this Edition. The Tables throughout have been revised and enlarged, and some new ones prepared. In some places the Conversations have been much extended. Many fresh subjects have been introduced, and several Conversations added; as, "On the new Planet, Neptune; the nineteen new Asteroids"—"Of the Diving-Boat"—"Of the Locomotive"—"Binocular Vision; the Stereoscope; the Pseudoscope;" "Magneto-Crystalline Action," &c.

Without departing from the original plan of the Author, I have endeavoured as much as possible to breathe into the conversations the spirit of modern science. Much more could have been profitably introduced had space permitted.

Charles V. Walker.

Bordyke, Tunbridge.
April, 1853.

PREFACE.

The Author of this volume feels himself extremely happy in the opportunity which this publication affords him of acknowledging the obligations he is under to the authors of "Practical Education," for the pleasure and instruction which he has derived from that valuable work. To this he is indebted for the idea of writing on the subject of Natural Philosophy for the use of children. How far his plan corresponds with that suggested by Mr. Edgeworth, in his chapter on Mechanics, must be left with a candid public to decide.

The Author conceives, at least, he shall be justified in asserting, that no introduction to natural and experimental philosophy has been attempted in a method so familiar and easy as that which he now offers to the public — none which appears to him so properly adapted to the capacities of young people of ten or eleven years of age; a period of life which, from the Author's own experience, he is confident is by no means too early to induce in children habits of scientific reasoning. In this opinion he is sanctioned by the authority of Mr. Edgeworth. "Parents," says he, "are anxious that children should be conversant with mechanics, and with what are called the mechanical powers. Certainly no species of knowledge is better suited to the taste and capacity of youth, and yet it seldom forms a part

of early instruction. Everybody talks of the lever, the wedge, and the pulley, but most people perceive that the notions which they have of their respective uses are unsatisfactory and indistinct; and many endeavour, at a late period of life, to acquire a scientific and exact knowledge of the effects that are produced by implements which are in everybody's hands, or that are absolutely necessary in the daily occupations of mankind."

The Author trusts that the whole work will be found a complete compendium of natural and experimental philosophy, not only adapted to the understandings of young people, but well calculated also to convey that kind of familiar instruction which is absolutely necessary before a person can attend public lectures in these branches of science with advantage. "If," says Mr. Edgeworth, speaking on this subject, "the lecturer does not communicate much of that knowledge which he endeavours to explain, it is not to be attributed either to his want of skill or to the insufficiency of his apparatus, but to the novelty of the terms which he is obliged to use. Ignorance of the language in which any science is taught is an insuperable bar to its being suddenly acquired: besides a precise knowledge of the meaning of terms, we must have an instantaneous idea excited in our minds whenever they are repeated; and as this can be acquired only by practice, it is impossible that philosophical lectures can be of much service to those who are not familiarly acquainted with the technical language in which they are delivered."*

* Mr. Edgeworth's chapter on Mechanics should be recommended to the attention of the reader, but the author feels unwilling to refer to a part of a work, the whole of which deserves the careful perusal of all persons engaged in the education of youth.

It is presumed that an attentive perusal of these Dialogues, in which the principal and most common terms of science are carefully explained, and illustrated by a variety of familiar examples, will be the means of obviating this objection with respect to persons who may be desirous of attending those public philosophical lectures to which the inhabitants of the metropolis have almost constant access.

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MECHANICS.

CONVERSATION I.

INTRODUCTION.

Father — Charles — Emma.

Charles. Father, you told sister Emma and me, that, after we had finished reading the "Evenings at Home," you would explain to us some of the principles of Natural Philosophy; will you begin this morning?

Father. Yes; and I shall indeed at all times take a delight in communicating to you the elements of useful knowledge; and the more so in proportion to the desire which you have of collecting and treasuring up such facts as may enable you to understand the operations of nature, as well as the works of ingenious artists. These, I trust, will lead you, insensibly, to admire the wisdom and goodness, by which the whole system of the universe is constructed and maintained.

Emma. But can philosophy be comprehended by children so young as we are? I thought that it had been the business of men, and of old men too.

F. The word *philosophy*, in its original sense, signifies a love or desire of wisdom; and you will not allow that you and your brother are too young to entertain such a desire.

E. So far from it, that the more knowledge I get, the better I seem to like it; and the number of new ideas which, with a little of your assistance, I have obtained from the "Evenings at Home," and the great pleasure which I have received from the perusal of these volumes, have made me wish to know more and more.

F. You will find very little in the introductory parts of natural and experimental philosophy requiring much more of your attention than many parts of that work, with which you have been so delighted. Besides, the study of natural philosophy improves and elevates the mind, by unfolding the magnificence and order, manifested in the construction of the mate-

rial world; while it offers the most striking proofs of the beneficence, the wisdom, and the power of the Creator.

C. But in some books of natural philosophy, into which I have occasionally looked, a number of new and uncommon words have perplexed me; I have also seen references to figures by means of large letters and small, the use of which I did not comprehend.

F. It is frequently a dangerous practice for young minds to dip into subjects, unless prepared for them by some previous knowledge: since it may create a distaste for the most interesting topics. Thus the books, which you now read with so much pleasure, would not have offered you the smallest entertainment a few years ago, when you must have spelt out almost every word in each page. The same sort of disgust will naturally be felt by persons who attempt to read works of science before the leading terms are explained and understood. The word *angle* is continually recurring in subjects of this sort; do you know what an angle is?

E. I do not think I do: will you explain what it means?

F. An *angle* is made by the opening of two straight* lines.

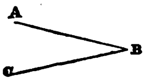


Fig. 1.

In this figure there are two straight lines A B and C B, meeting at the point B: the opening made by them is called an angle.

C. Whether that opening be small or great, is it still called an angle?

F. It is; your drawing compasses may familiarize to your mind the idea of an angle; the lines in this figure will aptly represent the legs of the compasses, and the point B the joint upon which they move or turn. Now you may open the legs to any distance you please, even so far that they shall form one straight line; in that position only they do *not* form an angle. In every other situation an angle is made by the opening of these legs; and the angle is said to be greater or less, as that opening is greater or less. An angle is, in fact, only another word for a *corner*.

E. Are not some angles called right angles?

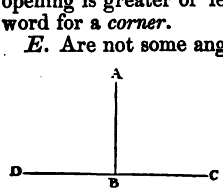


Fig. 2.

F. Angles are either *right*, *acute*, or *obtuse*. When the line A B meets another line D C, in such a manner as to make the angles A B D and A B C equal to one another, then those angles are called *right* angles. And the line A B is said to be perpendicular to D C. Hence to

* *Straight* lines, in works of science, are usually denominated *right* lines, and are the shortest distance from point to point.

be perpendicular to, or to make *right* angles with, a line, means one and the same thing.

C. Does it signify how you call the letters of an angle, or in what order you name them?

F. It is usual to call every angle by three letters; and the letter at the angular point must be always the middle of the three. There are cases, however, where an angle may be denominated by a single letter; thus the angle A B C may be called simply the angle B, for there is no danger of mistake, because there is but a single angle at the point B.

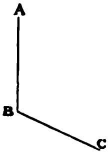


Fig. 3.

C. I understand this; for if, in fig. 2., I were to describe the angle by the letter B only, you would not know whether I meant the angle on the left, or that on the right of the perpendicular.

F. That is the precise reason why it is necessary in most descriptions to make use of three letters. An *acute* angle (fig. 1.) A B C is less than a right angle; and an *obtuse* (fig. 3.) angle A B C is greater than a right angle.

E. You see the reason now, Charles, why letters are placed against or by the figures, which puzzled you before.

C. I do; they are intended to distinguish the separate parts of each, in order to render the description of them easier, both to the author and the reader.

E. What is the difference between an angle and a triangle?

F. An angle is a *corner*, and a triangle a *space;* an angle depends upon the opening of two lines; but two straight lines cannot inclose a space; and a *triangle* A B C is a space bounded by three straight lines. It takes its name from the property of having three angles. There are various sorts of triangles; but it is not necessary to enter upon these particulars, as I do not wish to burthen your memories with more technical terms than we have occasion for.

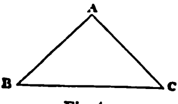


Fig. 4.

C. A triangle then is a space or figure containing three angles, and bounded by as many straight lines.

F. Yes, that description will answer our present purpose.

CONVERSATION II.

Of Matter.— Of the Divisibility of Matter.

F. Do you understand what philosophers mean, when they make use of the word matter?

E. Are not all things which we see and feel matter?

F. Everything, which is the object of our senses, is matter variously modified or arranged. The properties of matter are *extent*, it takes up room or space; *impenetrability*, two particles cannot be in the same space at the same time; *divisibility*, each particle can be mentally subdivided; *inertia*, it has no power of itself to move if at rest, or to stop if in motion; *mobility*, it can be transferred from place to place; *gravity*, or, as we commonly call it, weight.

E. I remember, that you told us something strange about the divisibility of matter, which you said might be continued without end.

F. I did, some time ago, mention this as a curious and interesting subject, and this is a very fit time for me to explain it.

C. Can matter indeed be infinitely divided, for I suppose that this is what is meant by a division without end?

F. Difficult as this may at first appear, yet I think it very capable of proof. Can you conceive of a particle of matter so small as not to have an upper and under surface?

C. Certainly, every portion of matter, however minute, must have two surfaces at least, and then I see that it follows of course that it is divisible; that is, the upper surface may be separated from the lower.

F. Your conclusion is just; and though there may be particles of matter too small for us actually to divide, yet this arises from the imperfection of our instruments; they must, nevertheless, in their nature, be divisible.

E. But you were to give us some remarkable instances of the minute division of matter.

F. A few years ago a lady spun a single pound of wool into a thread 168,000 yards long. And Mr. Boyle mentions, that two grains and a half of silk were spun into a thread 300 yards in length. If a pound of silver, which, you know, contains 5760 grains, and a single grain of gold be melted together, the gold will be equally diffused through the whole silver, insomuch that if one grain of the mass be dissolved in a liquid called *aqua fortis*, which is diluted nitric acid, the gold will fall to the bottom. By this experiment it is evident that a grain may be divided into 5761 visible parts, for only the 5761st part of the gold is contained in a single grain of the mass.

The gold-beaters, whom you have seen at work in the shops in Long Acre, can spread a grain of gold into a leaf containing 50 square inches, and this leaf may be readily divided into 500,000 parts, each of which is visible to the naked eye: and by the help of a microscope, which magnifies the area or surface of a body 100 times, the 100th part of each of these becomes

visible; that is, the 50 millionth part of a grain of gold will be visible, or a single grain of that metal may be divided into 50 millions of visible parts. But the gold which covers the silver wire used in making what is called gold lace, is spread over a much larger surface, yet it preserves, even if examined by a microscope, an uniform appearance. It has been calculated that one grain of gold under these circumstances would cover a surface of nearly thirty square yards.

The platinum wire stretched in the field of the telescope, by which the transit of stars is observed, is so fine that a mile of it hardly weighs a grain; and 150 pieces are only equal in size to a filament of raw silk. The small black point visible in an exhausted soap-bubble is so thin, that two and a half millions would be required to make the thickness of an inch. Four miles of spiders' web only weighs a grain.

The *natural* divisions of matter are still more surprising. In odoriferous bodies, such as camphor, musk, and assafœtida, a wonderful subtilty of parts is perceived; for though they are perpetually filling a considerable space with odoriferous particles, yet these bodies lose but a very small part of their weight in a great length of time.

Again, it is said by those who have examined with powerful microscopic glasses, and whose accuracy may be relied on, that there are more animals in the milt of a single cod-fish, than there are men on the whole earth, and that a single grain of sand is larger than four millions of these animals. Now, if it be admitted that these little animals are possessed of organised parts, such as a heart, stomach, muscles, veins, arteries, &c., and that they are possessed of a complete system of circulating fluids, similar to what is found in larger animals, we seem to approach to an idea of the infinite divisibility of matter. It has, indeed, been calculated that a particle of blood of one of these animalculæ is as much smaller than a globe one tenth of an inch in diameter, as that globe is smaller than the whole earth.

A small lump of sugar will impart a perceptible sweetness to a half-pint of tea, which contains about 30,000 drops. A needle point may be wetted by contact with one of these drops, and the drop will lose no apparent amount of liquid. How inconceivably small, then, must be the quantity of sugar contained in this minute quantity of tea.

I might enumerate many other instances of the same kind; but these, I doubt not, will be sufficient to convince you into what very minute parts matter is capable of being divided.

A late account, however, of animalculæ, observed by Captain, now Rev. Dr. Scoresby, in the Greenland seas, is so much to

our purpose, that I shall repeat it to you before we terminate our present conversation.

In July, 1818, while in those northern seas, Dr. Scoresby's vessel sailed for several leagues in water of a very uncommon appearance. The surface was variegated by large patches, and extensive streaks of a yellowish green colour. The colouring matter being found to be superficial, it was soon ascertained that it was constituted of animalculæ; and powerful microscopes were applied to their examination. In a single drop of water examined by a power of 28,224 (magnified superficies), there were 50 in number on an average, in each square of the micrometer glass of $\frac{1}{250}$th of an inch in diameter; and as the drop occupied a circle on a plate of glass containing 529 of these squares, there must have been in this single drop of water, taken at random out of the sea, and in a place by no means the most discoloured, about 26,450 animalculæ. Hence, reckoning 60 drops to a drachm, there would be a number in a gallon of water exceeding by one half the amount of the population of the whole terraqueous globe. How inconceivably minute must the vessels, organs, and fluids of these animals be! The diameter of several of these animalculæ did not exceed the 4000th part of an inch. A whale requires a sea to sport in: *a hundred and fifty millions of these would have ample scope for their evolutions in a tumbler of water.*

E. I think I now have a clear idea, papa, of infinite divisibility of matter.

F. Do not be too sure, dear girl; for this is one of the subjects on which our ideas can never be clear; they are very indistinct: some of the deepest thinkers have been obliged to hesitate on this subject.

CONVERSATION III.

Of the Attraction of Cohesion.

F. Well, my dear children, do you comprehend the several instances which I enumerated as examples of the minute division of matter?

E. Indeed, they very much excited our wonder and admiration; and yet, from the thinness of some leaf-gold which I once had, I can readily admit all you have said on that part of the subject. But I know not how to conceive of such small animals as you described; and I am still more puzzled in imagining, that animals so minute actually possess all the properties of the larger ones, such as a heart, veins, blood, &c.

F. I can, on the next bright morning, by the help of the solar microscope, show you very distinctly the circulation of the blood in a flea, which you may get from your little dog; and with better microscopes than those of which I am possessed, the same might be shown in animals still smaller than the flea; perhaps, even in those which are themselves invisible to the naked eye. But we shall converse more at large on this topic, when we are conversing upon Optics and the construction and uses of the Oxy-hydrogen Microscope. At present we will turn our thoughts to that principle in nature, which philosophers have agreed to call Attraction.

C. If there be no more difficulties in philosophy than we met with in our last lecture, I do not fear but that we shall, in general, be able to understand it? Are there not several kinds of attraction?

F. Yes, there are; two of which it will be sufficient for our present purpose to describe: the one is the *attraction of cohesion;* and the other that of *gravitation.* The *attraction of cohesion* is that power which keeps the parts of bodies together when they touch, and prevents them from separating, or which inclines the parts of bodies to unite, when they are placed sufficiently near to each other.

C. Is it then by the attraction of cohesion that the parts of this table, or of the penknife, are kept together?

F. Certainly; but you might have said the same of every other solid substance in the room; and it is in proportion to the different degrees of attraction, with which different substances are affected, that some bodies are hard, others soft, tough, &c. M. Musschenbroek, a philosopher in Holland, almost a century ago, took great pains in ascertaining the different degrees of cohesion, which belonged to various kinds of wood, metals, and many other substances. A short account of his experiments you will hereafter find in your own language, in Enfield's Institutes of Natural Philosophy: other experiments by M. Girard, and Mr. P. Barlow, will also deserve your attention.

C. You once showed me that two leaden bullets, having their surfaces scraped clean, might be made, with a sort of twisting pressure, to stick together with great force; you called that, I believe, the attraction of cohesion?

F. I did: though it is not unusual to distinguish between adhesion and cohesion. The particles of the same body *cohere;* contiguous surfaces of different bodies *adhere.* Some philosophers, who have made the experiment with great attention and accuracy, assert, that if the flat surfaces, which are presented to one another, be but a quarter of an inch in diameter and scraped

very smooth, and forcibly pressed together with a twist, a weight of a hundred pounds is frequently required to separate them.

As it is by this kind of attraction that the parts of solid bodies are kept together, so when any substance is separated or broken, it is only the attraction of cohesion that is overcome in that particular part.

E. Then, when I had the misfortune this morning, at breakfast, to let my saucer slip from my hands, by which it was broken into several pieces, was it only the attraction of cohesion that was overcome by the parts of the saucer being separated as it struck the ground?

F. Just so; for whether you unluckily break the china, or cut a stick with your knife, or melt lead over the fire, as your brother sometimes does, in order to make plummets; these, and a thousand other instances, which are continually occurring, are but examples in which the cohesion is overcome by the fall, the knife, or the fire.

E. The broken saucer being highly valued by mamma, she has taken the pains to join it again with whitelead; was this performed by means of the attraction of cohesion?

F. It was, my dear; and hence you will easily learn that many operations in cookery are in fact nothing more than different methods of causing this attraction to take place. Thus flour, by itself, has little or nothing of this principle; but when mixed with milk, or other liquids, to a proper consistency, the parts cohere strongly; and this cohesion in many instances becomes still stronger, by means of the heat applied to it in boiling or baking.

C. You put me in mind of the fable of the man blowing hot and cold; for in the instance of the *lead*, fire overcomes the attraction of cohesion; and the same power, heat, when applied to puddings, bread, &c., causes their parts to cohere more powerfully. How are we to understand this?

F. I will endeavour to remove your difficulty. Heat expands all bodies without exception, as you shall see before we have finished our lectures. Now the fire applied to metals in order to melt them, causes such an expansion, that the particles are thrown out of the sphere, or reach of each other's attraction: whereas the heat communicated in the operations of cookery is sufficient to expand the particles of flour, but is not enough to overcome the attraction of cohesion. Besides, the cook will tell you, that the heat of boiling would frequently disunite the parts of which her puddings are composed, if she did not take the precaution of inclosing them in a cloth, leaving them just room enough to expand without the liberty of breaking to

pieces; and the moment they are taken from the water they lose their superabundant heat and become solid.

E. When the cook makes broth for my little brother, it is the heat, then, which overcomes the attraction which the particles of meat have for each other; for I have seen her pour off the broth, and the meat is all in rags. But will not the heat overcome the attraction which the parts of the bones have for each other?

F. The heat of boiling water will never effect this; but a machine was invented several years ago, by Mr. Papin, for that purpose. It is called Papin's Digester, and is used in taverns, and in many private families, for the purpose of dissolving bones as completely as a lesser degree of heat will liquefy jelly. On some future day I will show you an engraving of this machine, and explain its different parts, which are extremely simple.*

CONVERSATION IV.

Of the Attraction of Cohesion.

F. I will now mention some other instances of the great law of adhesive or cohesive attraction, which occupied our thoughts in our last conversation. If two polished plates of marble, or brass, be put together, with a little oil between them to fill up the pores of their surfaces, they will cohere so powerfully as to require a very considerable force to separate them.—Two globules of quicksilver, placed very near to each other, will run together and form one large drop.—Drops of water will do the same.—Two circular pieces of cork placed upon water at about an inch distant will run together.—Balance a piece of smooth board on the end of a scale-beam; then let it lie flat on water, and five or six times its own weight will be required to separate it from the water.—If a small globule of quicksilver be laid on clean paper, and a piece of glass be brought into contact with it, the mercury will adhere to it, and be drawn away from the paper. But bring a larger globule into contact with the smaller one, and it will forsake the glass, and unite with the other quicksilver.

C. Is it not by means of the attraction of cohesion, that the little tea which is generally left at the bottom of the cup instantly ascends in the sugar when thrown into it?

F. The ascent of water or other liquids in sugar, sponge, and all porous bodies, is a species of this attraction, and is called *capillary*† *attraction;* it is thus denominated from the property

* See Pneumatics, Conversation XVIII.
† From *capillus*, the Latin word for *hair*.

which tubes of a very small bore, scarcely larger than a hair, have of causing water to stand above its level.

C. Is this property visible in no other tubes than those, the bores of which are so exceedingly fine?

F. Yes, it is very apparent in tubes whose diameters are one tenth of an inch or more, but the smaller the bore, the higher the fluid rises; for it ascends, in all instances, till the weight of the column of water in the tube balances, or is equal to, the attraction of the tube. By immersing tubes of different bores in a vessel of coloured water, you will see how the water rises much higher in the smaller tubes than in the larger. The water will rise a quarter of an inch, and there remain suspended, in a tube whose bore is about one eighth of an inch in diameter.

This kind of attraction is well illustrated by taking two pieces of glass joined together at the side B C, and kept a little open at the opposite side A D, by a small piece of cork E. In this position, immerse them in a dish of coloured water F G, and you will observe that the attraction of the glass at, and near B C, will cause the fluid to ascend to B; whereas about the parts D it scarcely rises above the level of the water in the vessel.

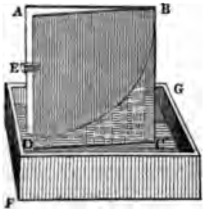


Fig. 5.

C. I see that a curve is formed by the water.

F. There is; and to this curve, called a hyperbole, belong many curious properties, as you will hereafter be able to investigate for yourself.

E. Is it not upon the principle of the attraction of cohesion that carpenters glue their work together?

F. It is upon this principle that carpenters and cabinet-makers make use of glue; that braziers, tinmen, plumbers, &c., solder their metals; and that smiths unite different bars of iron by means of heat. These and a thousand other operations, which we continually witness, depend on the same principle as that which induced your mother to use the whitelead in mending her saucer. But, by the by, though whitelead is frequently used as a cement for broken china, glass, and earthenware, yet, if the vessels are to be brought again into use, it is not a proper cement, being an active poison; besides, one much stronger has been discovered, I believe, by a very able and ingenious philosopher, the late Dr. Ingenhouz; at least I had it from him several years ago: it consists simply of a mixture of quicklime and Gloucester cheese, rendered soft by warm water, and worked up to a proper consistency.

E. What! do such great philosophers, as I have heard you say Dr. Ingenhouz was, attend to such trifling things as these?

F. He was a man deeply skilled in many branches of science; and I hope that you and your brother will one day make yourselves acquainted with many of his important discoveries. But no real philosopher will consider it beneath his attention to add to the conveniences of life.

C. This attraction of cohesion seems to pervade the whole of nature.

F. It does, but you will not forget that it acts only at very small distances. Some bodies indeed appear to possess a power the reverse of the attraction of cohesion.

E. What is that?

F. It is called repulsion.—Thus water repels most bodies till they are wet. A small needle carefully placed on water will swim, although the iron of which it is made is much heavier than water: flies walk upon water without wetting their feet. The drops of dew which appear in a morning on plants, particularly on cabbage plants, assume a globular form, from the mutual attraction between the water: and upon examination it will be found that the drops do not touch the leaves, for they will roll off in compact bodies, which could not be the case if there subsisted any degree of attraction between the water and the leaf.

If a small thin piece of iron were laid upon quicksilver, the repulsion between the different metals will cause the surface of the quicksilver near the iron to be depressed.

The repelling force of the particles of a fluid is but small; therefore if a fluid be divided it easily unites again. But if a glass or any hard substance be broken, the parts cannot be made to cohere without first being moistened, because the repulsion is too great to admit of a reunion.

The repelling force between water and oil, is likewise so great that it is impossible to mix them in such a manner that they shall not separate again.

If a ball of light wood be dipped in oil, and then put into water, the water will recede so as to form a sort of channel round the ball.

C. Why do cane, steel, and many other things, bear to be bent without breaking, and, when set at liberty, recover their original form?

F. That a piece of thin steel, or cane, recovers its usual form after being bent, is owing to a certain power called *elasticity;* which may perhaps arise from the particles of those bodies, though disturbed, not being drawn out of each other's attraction;

therefore, as soon as the force upon them ceases to act, they restore themselves to their former position.—But our half-hour is expired; I must leave you.

CONVERSATION V.

Of the Attraction of Gravitation.

F. We will now proceed to discuss another very important general principle in nature; the *attraction of gravitation* or, as it is frequently termed, *gravity*, which is that power by which *distant* bodies tend towards each other. Of this we have perpetual instances in the falling of bodies to the earth.

C. Am I then to understand that whether this marble falls from my hand; or a loose brick from the top of the house; or an apple fro n the tree in the orchard, that all these happen by the attraction of gravity?

F. It is by the power which is commonly expressed under the term *gravity*, that all bodies whatever have a tendency to the earth, and, unless supported, will fall in lines nearly perpendicular to its surface. This tendency or disposition to fall represents the weight. But gravity and weight do not mean precisely the same thing: gravity is the weight of a given bulk of one body, compared with the weight of a given bulk of another; weight is the actual weight, without comparison with another body.

E. But are not smoke, vapour, and other light bodies which we see ascend, exceptions to the general rule?

F. It appears so at first sight; and it was formerly received as a general opinion, that smoke, vapour, &c. possessed no weight: the invention of the air-pump has shown the fallacy of this notion; for in an exhausted receiver, that is, in a glass jar from which the air is taken away by means of the air-pump, smoke and vapour descend by their own weight as completely as a piece of lead. When we come to converse on the subject of Pneumatics and Hydrostatics, you will understand that the reason why smoke and other bodies ascend is simply because they are lighter than the atmosphere which surrounds them, and the moment they reach that part of it which has the same gravity with themselves they cease to rise.

C. Is it then by this power that all terrestrial bodies remain firm on the earth?

F. By gravity, bodies on all parts of the earth (which you know is of a globular form) are kept on its surface because they all, wherever situated, tend to the centre; and, since all have a

tendency to the centre, the inhabitants of New Zealand, although nearly opposite to our feet, stand as firmly as we do in Great Britain.

C. This is difficult to comprehend: nevertheless, if bodies on all parts of the surface of the earth have a tendency to the centre, there seems no reason why bodies should not stand firm on one part as well as another. Does this power of gravity act alike on all bodies?

F. It does, without any regard to their figure or size; for attraction or gravity acts upon bodies in proportion to the quantity of matter which they contain, that is, four times a greater force of gravity is exerted upon a body weighing four pounds, than upon one of a single pound. The consequence of this principle is, that all bodies at equal distances from the earth fall with equal velocity.

E. What do you mean, papa, by *velocity?*

F. I will explain it by an example or two: if you and Charles set out together, and *you* walk a mile in half an hour, but *he* walk or run two miles in the same time, how much more swiftly will he go than you?

E. Twice as swiftly.

F. He does, because, *in the same time*, he passes over twice as much space; therefore we say his velocity is twice as great as yours. Suppose a ball, fired from a cannon, pass through 800 feet in a second of time; and if, in the same time, your brother's arrow pass through 100 feet only, how much more swiftly does the cannon ball fly than the arrow?

E. Eight times swifter.

F. Then it has eight times the velocity of the arrow; and hence you understand that swiftness and velocity are synonymous terms, and that the velocity of a body is measured by the space it passes over in a given time, as a second, a minute, an hour, &c.

E. If I let a piece of metal, as a penny-piece, and a feather, fall from my hand at the same time, the penny will reach the ground much sooner than the feather. Now how do you account for this, if all bodies are equally affected by gravitation, and descend with equal velocities, when at the same distance from the earth?

F. Though the penny and feather will not, in the open air, fall with equal velocity, yet, if the air be taken away, which is easily done by a little apparatus connected with the air-pump, they will descend in the same time. Therefore the true reason why light and heavy bodies do not fall with equal velocities is, that the *former* in proportion to its weight, meets with a much greater resistance from the air than the *latter*.

C. It is then, I imagine, from the same cause, that if I drop the penny and a piece of light wood into a vessel of water, the penny shall reach the bottom, but the wood, after descending a small way, rises to the surface.

F. In this case the resisting medium is water instead of air, and the copper, being about nine times heavier than its bulk of water, falls to the bottom with but little apparent resistance. But the wood, being much lighter than water, cannot sink in it; therefore, though by its *momentum** it sinks a small distance, yet as soon as that is overcome by the resisting medium, that is, the water, it rises to the surface, being the lighter substance.

CONVERSATION VI.

Of the Attraction of Gravitation.

E. The term *momentum* which you made use of yesterday, is another which I do not as yet understand.

F. If you have understood what I have said respecting the velocity of moving bodies, you will easily comprehend what is meant by the word momentum.

The *momentum*, or moving force of a body, is measured by its weight multiplied by its velocity. You may, for instance, place this pound weight upon a china plate without any danger of breaking, but if you let it fall from the height of only a few inches, it will dash the china to pieces. In the first case, the plate has only the pound weight to sustain; in the other, the weight must be multiplied by the velocity it has acquired during its fall.

If a ball *a*, lean against the obstacle *b*, it will not be able to overturn it, but if it be taken up to *c*, and suffered to roll down the inclined plane, A B, against *b*, it may probably overthrow it; in the former case *b* would only have to resist the weight of the ball *a*; in the latter it has to resist the weight multiplied by its motion or velocity.

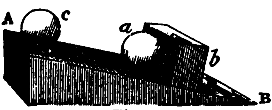


Fig. 6.

C. Then the momentum of a small body, whose velocity is very great, may be equal to that of a very large body with a slow velocity.

F. It may; and hence you see the reason why immense battering-rams, used by the ancients, in the art of war, have given place to cannon-balls of but a few pounds' weight.

* The explanation of this term will be found in the next Conversation.

C. I do; for what is wanting in weight is made up by velocity.

F. Can you tell me what velocity a cannon-ball of 28 pounds must have to effect the same purposes as would be produced by a battering-ram of 15,000 pounds weight, and which, by manual strength, could be moved at the rate of only two feet in a second of time?

C. I think I can: the *momentum* of the battering-ram must be estimated by its weight, multiplied into the space passed over in a second, which is 15,000 multiplied by two feet, equal to 30,000; now if this momentum, which must also be that of the cannon-ball, be divided by the weight of the ball, it will give the velocity required; and 30,000 divided by 28 will be for the quotient 1072 nearly, which is the number of feet the cannon-ball must pass over in a second of time, in order that the momenta of the battering-ram and the ball may be equal, or, in other words, that they may have the same effect in beating down an enemy's wall.

E. I now fully comprehend what the momentum of a body is; for if I let a common trap-ball accidentally fall from my hand upon my foot, it occasions more pain than the mere pressure of a weight several times heavier than the ball.

C. If the attraction of gravitation be a power by which bodies in general tend towards each other, why do all bodies tend to the earth as a centre?

F. I have already told you, that, by the great law of gravitation, the attraction of all bodies is in proportion to the quantity of matter which they contain. Now the earth being so immensely large in comparison of all other substances in its vicinity, destroys the effect of this attraction between smaller bodies, by bringing them all to itself.—If two balls are let fall from a high tower at a small distance apart, though they have an attraction for one another, yet it will be as nothing when compared with the attraction by which they are both impelled to the earth, and consequently the tendency which they mutually have of approaching one another will not be perceived in the fall. If, however, any two bodies were placed in free space, and out of the sphere of the earth's attraction, they would, in that case, assuredly approach each other, and that with increased velocity as they came nearer. Indeed, it has been found that a plumb-line held near a perpendicular mountain deviates from a vertical direction, by the attraction of the mountain for the weight.

C. According to this, the earth ought to move towards falling bodies, as well as they move to it.

F. It ought, and in just theory, it does; but when you calculate how many million of times larger the earth is than any-

thing belonging to it, and if you reckon, at the same time, the small distances from which bodies can fall, you will know that the point where the falling bodies and earth will meet, is removed only to an indefinitely small distance from its surface, a distance much too small to be conceived by the human imagination.

As all bodies on or near the earth tend to the centre of that body, so the earth, and all the planets, with their several moons, as we shall see by and by, tend to the sun; as the body to which the whole and every part of the solar system is attracted.

We will resume the subject of gravity to-morrow.

CONVERSATION VII.

Of the Attraction of Gravitation.

E. Has the attraction of gravitation the same effect on all bodies, whatever be their distance from the earth?

F. No; this, like every power which proceeds from a centre, decreases as the squares of the distances from that centre increase.

E. I fear that I shall not understand this, unless you illustrate it by examples.

F. Suppose you are reading at the distance of one foot from a candle, and that you receive a certain quantity of light on your book: now if you remove to the distance of two feet from the candle, you will, by a similar law, receive four times less light than you had before; here, then, though you have increased your distance but twofold, yet the light is diminished fourfold, because four is the square of two, or two multiplied by itself. If, instead of removing two feet from the candle, you take your station at 3, 4, 5, or 6 feet distance, you will then receive at the different distances, 9, 16, 25, 36 times less light than when you were within a single foot from the candle, for these, as you know, are the squares of the numbers 3, 4, 5, and 6. The same is applicable to the heat imparted by a fire; at the distance of one yard from which a person will enjoy four times as much heat as he who sits or stands two yards from it; and nine times as much as one who should be removed to the distance of three yards.

C. Is then the attraction of gravity four times less at a yard distance from the earth, than it is at the surface?

F. No; whatever be the cause of attraction, which to this day remains undiscovered, it is so adjusted under the surface as though it acted from the *centre* of the earth, and not from its surface, and hence the difference of the power of gravity can scarcely be discerned at the small distances to which we have

access; for a mile or two, which is much higher than, in general, we have opportunities of making experiments, is very little in comparison of 4000 miles, the distance of the centre from the surface of the earth: and the squares of 4000 and 4002 differ still less when compared with either square. But could we ascend 4000 miles above the earth, and of course be double the distance that we now are from the centre, we should there find that the attractive force would be but one fourth of what it is here; or, in other words, that a body which, at the surface of the earth, weighs one pound, and by the force of gravity falls through sixteen feet in a second of time, would, at 4000 miles above the earth, weigh but a quarter of a pound, and fall through only four feet in a second.*

E. How is that known, papa; for nobody ever was there?

F. You are right, my dear; for the greatest height that has been attained by the most daring voyagers in a balloon, is nothing in comparison with this. However, I will try to explain in what manner philosophers have come by their knowledge on this subject.

The moon is a heavy body connected with the earth by this bond of attraction; and, by the most accurate observations, it is known to be obedient to the same laws as other heavy bodies are: its distance is also clearly ascertained, being about 240,000 miles, or equal to about sixty semi-diameters of the earth, and of course the earth's attraction upon the moon ought to diminish in the proportion of the square of this distance; that is, it ought to be 60 times 60, or 3600 times less at the moon than it is at the surface of the earth. And this is actually the case: it is proved by a certain deviation in the moon's course, which you will comprehend better when you become acquainted with astronomy.

Again, the earth is not a perfect sphere, but a spheroid, that is, rather flat at the two ends called the poles, and the distance from the centre to the poles is about 12 or 13 miles less than its distance from the centre to the equator; consequently bodies ought to be something heavier at and near the poles than they are at the equator, which is also found to be the case. Hence it is inferred that the attraction of gravitation varies at all distances from the centre of the earth, in proportion as the squares of those distances increase.†

* Ex. Suppose it were required to find the weight of a leaden ball, at the top of a mountain three miles high, which on the surface of the earth weighs 20 lb. —

If the semi-diameter of the earth be taken at 4000, then add to this the height of the mountain, and say as the square of 4003 is to the square of 4000, so is 20 lb. to a fourth proportional: or as 16,024,009 : 16,000,000 : : 20 : 19·97; or something more than 19 lb. 15½ oz. which is the weight of the leaden ball at the top of the mountain.

† See Astronomy, Conversation VI.

C. It seems very surprising that philosophers, who have discovered so many things, have not been able to find out the cause of gravity. Had Sir Isaac Newton been asked why a marble, dropped from the hand, falls to the ground, could he not have assigned a reason?

F. That great man, probably the greatest man that ever adorned this world, was as modest as he was great, and he would have told you he knew not the cause.

The late learned Dr. Price, in a work which he published more than forty years ago, asks, "Who does not remember a time when he would have wondered at the question, *why does water run down hill?* What ignorant man is there who is not persuaded that he understands this perfectly? But every *improved* man knows it to be a question he cannot answer." For the descent of water, like that of other heavy bodies, depends upon the attraction of gravitation, the cause of which is still involved in darkness.

E. You just now said that heavy bodies by the force of gravity fall about sixteen feet in a second of time; is that always the case?

F. Yes; all bodies near the surface of the earth in our latitude fall at that rate in the first second of time; but as the attraction of gravitation is continually acting, so the velocity of falling bodies is an increasing, or, as it is usually called, an *accelerating* velocity. It is found by very accurate experiments that a body descending from a considerable height by the force of gravity, falls 16 feet in the first second of time; 3 times 16 feet in the next; 5 times 16 feet in the third; 7 times 16 in the fourth second of time; and so on, continually increasing according to the odd numbers, 1, 3, 5, 7, 9, 11, &c. In our latitude the true distance fallen in the first second is $16\frac{1}{12}$ feet; and by reason of the centrifugal force, this space varies a little in different latitudes. But this is not the proper time to explain to you these minutiæ.

CONVERSATION VIII.

Of the Attraction of Gravitation.

E. Would a ball of twenty pounds weight here, really weigh half an ounce less on the top of a mountain three miles high?

F. Certainly; but you would not be able to ascertain it by means of a pair of scales and another weight, because both weights being in similar situations, would lose equal portions of their gravity.

E. How, then, would you make the experiment?

F. By means of one of those steel spiral-spring instruments which you have seen occasionally used, the fact might be ascertained.

C. I think, from what you told us yesterday, that with the assistance of your stop-watch, I could tell the height of any place, by observing the number of seconds that a marble or other heavy body would take in falling from that height.

F. How would you perform the calculation?

C. I should go through the multiplications according to the number of seconds, and then add them together.

F. Explain yourself more particularly. Supposing you were to let a marble or penny-piece fall down that deep well which we saw in the brick-field near Ramsgate, and that it was exactly five seconds in the descent, what would be the depth of the well?

C. In the first second it would fall 16 feet; in the next 3 times 16, or 48 feet; in the third 5 times 16, or 80 feet; in the fourth 7 times 16, or 112 feet; and in the fifth second 9 times 16, or 144 feet; now if I add 16, 48, 80, 112, and 144 together, the sum will be 400 feet, which, according to your rule, is the depth of the well. But was the well so deep?

F. I do not think it was, but we did not make the experiment; should we ever go to that place again, you may satisfy your curiosity. You recollect that at Dover Castle we were told of a well there 360 feet deep.

Though your calculation was accurate, yet it was not done as nature effects her operations, that is, in the shortest way.

C. I should be pleased to know an easier method; this, however, is very simple; it required nothing but multiplication and addition.

F. True; but suppose I had given you an example in which the number of seconds had been fifty instead of five, the work would probably have taken you near an hour to perform it; whereas by the rule which I am going to give, it might have been done in half a minute.

C. Pray let me have it; I hope it will be easily remembered.

F. It will: I think it cannot be forgotten after it is once understood. The rule is this, "*the spaces described by a body falling freely from a state of rest, increase as the* SQUARES *of the times increase.*" Consequently you have only to square the number of seconds, that is, to multiply the number into itself, and then multiply that again by sixteen feet, the space which it describes in the first second, and you have the required answer. Now try the example of the *well*.

C. The square of 5, for the time, is 25, which, multiplied by 16, gives 400, just as I brought it out before. Now if the seconds had been 50, the answer would be 50 times 50, which is 2500, and this multiplied by 16, gives 40,000 for the space required.

F. I will now ask your sister a question, to try how she has understood this subject. Suppose you observe by this watch that the time of the flight of your brother's arrow is exactly six seconds, to what height does it rise?

E. This is a different question, because here the *ascent* as well as the *fall* of the arrow is to be considered.

F. But you will remember that the time of the ascent is always equal to that of the descent; for as the velocity of the descent is generated by the force of gravity, so is the velocity of the ascent destroyed by the same force.

E. Then the arrow was three seconds only in falling; now the square of three is 9, which, multiplied by 16, for the number of feet described in the first second, is equal to 144 feet, the height to which it rose.

F. Now, Charles, if I get you a bow which will carry an arrow so high as to be fourteen seconds in its flight, can you tell me the height to which it ascends?

C. I can now answer you without hesitation: it will be 7 seconds in falling, the square of which is 49, and this again multiplied by 16, will give 784 feet, or rather more than 261 yards, for the answer.

F. If you will now consider the example which you did the long way, you will see that the rule which I have given you answers very completely. In the 1st second the body fell 16 feet, and in the next 48; these added together make 64, which is the square of the 2 seconds multiplied by 16. The same holds true of the first 3 seconds, for in the 3d second it fell 80 feet, which added to the 64, give 144, equal to the square of 3 multiplied by 16. Again, in the 4th second it fell 112 feet, which added to 144, give 256, equal to the square of 4 multiplied by 16; and in the 5th second it fell 144 feet, which added to 256, give 400, equal to the square of 5 multiplied by 16. Thus you will find the rule hold in all cases, *that the space described by bodies falling freely from a state of rest, increases as the* SQUARES *of the time increase.*

C. I think I shall not forget the rule. I will also show my cousin Henry how he may know the height to which his bow will carry.

F. The surest way of keeping what knowledge we have obtained is by communicating it to our friends.

C. It is a very pleasant circumstance, indeed, that the giving

away is the best method of keeping, for I am sure the being able to oblige one's friends is a most delightful thing.

F. Your liberal sentiments are highly gratifying to me; fain would I confirm them by adding more to your stock of knowledge. And, in reference to the subject now before us, it may be necessary to guard you against the notion, that because the *spaces* described by falling bodies are as the squares of the times, the *velocities* increase in the same ratio. This is not the case. The velocity acquired by a body falling freely, at the end of the 1st second of its motion, is such as, if it continued uniform, would carry it over 32 feet in the next second. And in all succeeding intervals the velocities are *as the times:* that is, at the end of 2, 3, 4, and 5 seconds, the velocities acquired will be respectively, twice, thrice, four times, and five times 32 feet; or, 64, 96, 128, and 160 feet.

E. Before we quit this part of the subject, papa, let me try if I thoroughly comprehend your meaning. A falling body having been in motion 4 seconds, will have descended 256 feet, and will then have a velocity of 128 feet; but the motion still accelerates and causes the body to pass over nine times 16, or 144 feet, in the 5th second, making in all 400 feet: it will then have acquired a velocity of 5 times 32, or 160 feet in a second, which if it continued uniform for another 5 seconds, would carry the body over 800 feet, or just *twice* the space described by the body in the first 5 seconds, during which its motion was equably accelerated by gravity.

F. You have convinced me, my dear Emma, that you have most accurately caught the distinction I wished you to understand. If you go to the library, and in Gregory's 'Mechanics,' or one of the Cyclopædias, look to the account of Attwood's *Machine*, you will find a description of some curious experiments by which the whole will be rendered evident to your *eye* as well as to *the eye of the mind.*

CONVERSATION IX.

Of the Centre of Gravity.

F. We are now going to treat upon the *Centre of Gravity*, which is that point of a body in which its whole weight is, as it were, concentrated, and upon which, if the body be freely suspended, it will rest; and in all other positions the centre of gravity will endeavour to descend to the lowest place to which it can get.

C. All bodies, then, of whatever shape, have a centre of gravity?

F. They have: and if you conceive a line drawn from the centre of gravity of a body towards the centre of the earth, that line is called the *line of direction*, along which every body, not supported, endeavours to fall. If the *line of direction* fall within the base, it will stand; if not, it will fall.

If I place the piece of wood A on the edge of a table, and from a pin *a* at its centre of gravity hang a little weight *b*, the line of direction *a b* falls within the base, and therefore, though the wood leans, yet it stands secure. But if upon A, another piece of wood B be placed, it is evident that the centre of gravity of the whole will be now raised to *c*, at which point, if a weight be hung, and it be found that the line of direction falls outside the base, the body must fall.

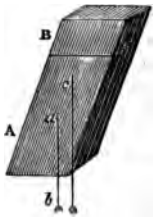


Fig. 7.

E. I think I now see the reason of the advice which you gave me, when going across the Thames in a boat.

F. I told you that if you were overtaken by a storm or a squall, while on the water, you must not let your fears induce you to rise from your seat; because you would thus elevate the centre of gravity, and thereby, as is evident by the last experiment, increase the danger: whereas, if, at the moment of danger, all on board lie on the bottom, the risk would be diminished, by bringing the centre of gravity much lower.

E. Surely then, papa, those coaches, whose tops are loaded with a dozen or more people, cannot be safe for the passengers?

F. They are very unsafe; and that they are not more frequently overturned is due to the good or even roads of this country; a corner or sloping road would throw the centre of gravity beyond the base, and they would inevitably fall.

C. I understand then, that the nearer the centre of gravity is to the base of a body, the firmer it will stand?

F. Certainly; and hence you see why conical bodies stand so firmly on their bases, for the tops being small in comparison of the lower parts, the centre of gravity is very low; and if the cone be upright or perpendicular, the line of direction falls in the middle of the base, which is another fundamental property of steadiness in bodies. For the broader the base, and the nearer the line of direction is to the middle of it, the more firmly does a body stand; but if the line of direction fall near the edge, the body is easily overthrown.

C. Is that the reason why a ball is so easily rolled along a horizontal plane?

F. It is; for, in all spherical bodies, the base is but a point; consequently the smallest force is sufficient to remove the line of direction out of it. Hence, heavy bodies situated on an inclined plane will, while the line of direction falls within the base, slide down upon the plane: but they will roll when that line falls without the base. The body A will slide down the plane D E, but the bodies B and C will roll down it.

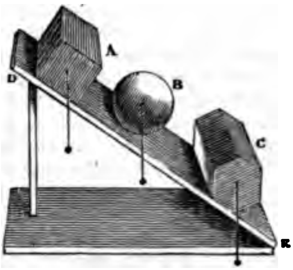


Fig. 8.

E. I have seen buildings lean very much out of a straight line; why do they not fall?

F. It does not follow because a building leans, that the centre of gravity does not fall within the base. There is a high tower at Pisa, a town in Italy, which leans fifteen feet out of the perpendicular; strangers tremble in passing by it; still it is found by experiment that the line of direction falls within its base, and therefore it will stand so long as its materials hold together.

A wall at Bridgenorth, in Shropshire, which I have seen, stands in a similar situation; but so long as a line *c b*, let fall from the centre of gravity *c* of the building A B, passes within the base C D, it will remain firm, unless the materials, with which it is built, go to decay.

Fig. 9.

C. It must be of great use in many cases to know the method of finding the centre of gravity in different kinds of bodies.

F. There are many easy rules for this with respect to all manageable bodies: I will mention one which depends on the

property the centre of gravity has, of always endeavouring to descend to the lowest point.

If a body A be freely suspended on a pin *a*, and a plumb-line *a* B be hung by the same pin, it will pass through the centre of gravity, for that centre is not in the lowest point, till it fall in the same line as the plumb-line. Mark the line *a* B; then hang the body up by any other point, as D, with the plumb-line D E, which will also pass through the centre of gravity for the same reason as before; and therefore, as the centre of gravity is somewhere in *a* B, and also in some point of D E, it must be in the point C, where those lines cross.

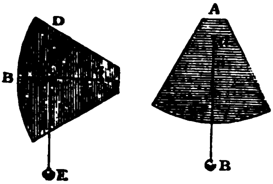


Fig. 10.

CONVERSATION X.

Of the Centre of Gravity.

C. How do those people who have to load carts and waggons with light goods, as hay, wool, &c., know where to find the centre of gravity?

F. Perhaps the generality of them never heard of such a principle; and it seems surprising that they should nevertheless make up their loads with such accuracy as to keep the line of direction in or near the middle of the base.

E. I have sometimes trembled to pass by the hop-waggons which we have met on the Kent Road.

F. And without any impeachment of your courage; for they are loaded to such an enormous height, that they totter every inch of the road. It would be impossible for one of these to pass with tolerable security along a road much inclined; the centre of gravity being removed so high above the body of the carriage, a small declination on one side or the other would throw the line of direction out of the base.

E. When my brother James falls about, it is because he cannot keep the centre of gravity between his feet?

F. That is the precise reason why any person, whether old or young, falls. And hence you learn that a man stands much firmer with his feet a little apart than if they were quite close, for by separating them he increases the base. Hence, also, the difficulty of sustaining a tall body, as a walking-cane, upon a narrow foundation.

E. How do rope and wire-dancers, whom I have seen at the Circus, manage to balance themselves?

F. They generally hold a long pole, with weights at each end, across a rope on which they dance, keeping their eyes fixed on some object parallel to the rope, by which means they know when their centre of gravity declines to one side of the rope or the other, and thus, by the help of the pole, they are enabled to keep the centre of gravity over the base, narrow as it is. It is not however rope-dancers only that pay attention to this principle, but the most common actions of persons in general are regulated by it.

C. In what respects?

F. We bend forward when we go up stairs, or rise from our chair, in order to bring the line of direction towards our feet. For the same reason, a man carrying a burden on his back leans forward; and backward if he carries it on his breast. If the load be placed on one shoulder, he leans to the other. If we slip or tumble with one foot, we naturally extend the opposite arm, making the same use of it as the rope-dancer of his pole.

This property of the centre of gravity always tending to descend, will account for appearances which are sometimes exhibited to excite the surprise of spectators.

E. What are those?

F. One is, that of a double cone, appearing to roll up two inclined planes, forming an angle with each other; for as it rolls it sinks between them, and by that means the centre of gravity is actually descending.

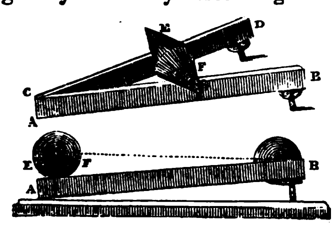


Fig. 11.

Let a body E F, consisting of two equal cones united at their bases, be placed upon the edges of two straight smooth rulers, A B and C D, which at one end meet in an angle at A, and rest on a horizontal plane, and at the other are raised a little above the plane; the body will roll towards the elevated end of the rulers, and appear to ascend; the parts of the cone that rest on the rulers becoming smaller as they go over a large opening, and thus letting it down, the centre of gravity descends. But you must remember that the height of the planes must be less than the radius of the base of the cone.

C. Is it upon this principle that a cylinder is made to roll up hill?

F. Yes, it is; but this can only be effected to a small distance. If a cylinder of pasteboard, or very light wood, A B, having its centre of gravity at *c*, be placed on the inclined plane C D, it will roll down the inclined plane, because a line of direction from that centre lies out of the base. If I now fill the little hole *o* above with a plug of lead, it will roll up the inclined plane, till the lead gets near the base, where it will lie still; because the centre of gravity, by means of the lead, is removed from *c* towards the plug, and therefore is descending, though the cylinder is ascending.

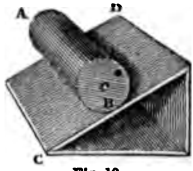


Fig. 12.

E. I remember our surprise at the circus to see a man stand upon a large globe, and while upon it roll it up a long incline and down again. I suppose this was on the same principle.

F. Yes: with one foot he pressed upon the distant side, and so made the centre of gravity continually to be outside the base, in the direction in which he desired to move; and he skilfully applied the other foot to the surface, in such a direction as to act favourably with the other.

Before I put an end to this subject, I will show you another experiment, which, without understanding the principle of the centre of gravity, cannot be explained. Upon this stick A, which, of itself, would fall, because its centre of gravity hangs over the table E F, I suspend a bucket B, fixing another stick *a*, one end in a notch between A and *k*, and the other against the inside of the pail at the bottom. Now you will see that the bucket will, in this position, be supported though filled with water. For the bucket being pushed a little out of the perpendicular by the stick *a*, the centre of gravity of the whole is brought under the table, and is consequently supported by it.

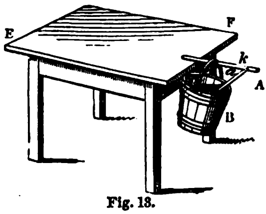


Fig. 13.

The knowledge of the principle of the centre of gravity in bodies will enable you to explain the structure of a variety of toys which are put into the hands of children, such as the *little sawyer*, *rope-dancer*, *tumbler*, *&c*

CONVERSATION XI.

On the Laws of Motion.

C. Are you now going, papa, to describe those machines which you call *mechanical powers?*

F. We must, I believe, defer that a day or two longer, as I have a few more general principles with which I wish you previously to be acquainted.

E. What are these?

F. In the first place, you must well understand what are denominated the three general laws of motion; the *first* of which is, "*that every body will continue in its state of rest or of uniform motion, until it is compelled by some force to change its state.*" This constitutes what is denominated the *inertia* or inactivity of matter. And it may be observed that a change never happens in the motion of any body, without an equal and opposite change in the motion of some other body.

C. There is, no difficulty of conceiving that a body, as this inkstand, in a state of rest, must always remain so, if no external force be impressed upon it to give it motion. But I know of no example which will lead me to suppose that a body once put into motion would of itself continue so.

F. You will, I think, presently admit the latter part of the assertion, as well as the former, although it cannot be established by experiment.

E. I shall be glad to hear how this is.

F. You will not deny that the ball, which you strike from the trap, has no more power either to destroy its motion, or to cause any change in its velocity, than it has to change its shape?

C. Certainly: nevertheless, in a few seconds after I have struck the ball with all my force, it falls to the ground, and then stops.

F. Do you find no difference in the time that is taken up before it comes to rest, even supposing your blow the same?

C. Yes, if I am playing on the grass it rolls to a less distance than when I play on the smooth gravel.

F. You find a like difference when you are playing at marbles, if you play in the gravel court, or on the even pavement in the arcade.

C. The marbles run so easily on the smooth stones in the arcade, that we can scarcely shoot with a force small enough.

E. And I remember Charles and my cousin were, last winter, trying how far they could shoot their marbles along the ice in the canal; and they went a prodigious distance in comparison

of that which they would have gone on the gravel, or even on the pavement in the arcade.

F. Now these instances properly applied will convince you, that a body once put into motion would go on for ever, if it were not compelled by some external force to change its state.

C. I perceive what you are going to say:—it is the rubbing or friction of the marbles against the ground which does the business. For on the pavement there are fewer obstacles than on the gravel, and fewer on the ice than on the pavement; and hence you would lead us to conclude, that if all obstacles were removed they might proceed on for ever. But what are we to say of the ball—what stops that?

F. Besides friction, there is another and still more important circumstance to be taken into consideration, which affects the ball, marbles, and every body in motion.

C. I understand you; that is the attraction of gravitation.

F. It is; for from what we said when we conversed on that subject, it appeared that gravity has a tendency to bring every body in motion to the earth,; consequently, in a few seconds, your ball must come to the ground by that cause alone; but besides the attraction of gravitation, there is the resistance of the air, through which the ball moves.

E. That cannot be much, I think.

F. Perhaps, with regard to the ball struck from your brother's trap, it is of no great consideration, because the velocity is but small; but in all great velocities, as that of a ball from a musket or cannon, there will be a material difference between the theory and practice, if it be neglected in the calculation. Move your mamma's riding-whip through the air slowly, and you observe nothing to remind you that there is this resisting medium; but if you swing it with considerable swiftness, the noise which it occasions will inform you of the resistance it meets with from something, which is the atmosphere.

C. If I now understand you, the force which compels a body in motion to stop, is of three kinds: 1, the attraction of gravitation; 2, the resistance of the air; and 3, the resistance it meets with from friction.

F. You are quite right.

C. I have no difficulty in conceiving that a body in motion will not come to a state of rest, till it is brought to it by an external force, acting upon it in some way or other. I have seen a gentleman, when skating on very slippery ice, go a great way without any exertion to himself; but where the ice was rough, he could not go half the distance, without making fresh efforts.

F. I will mention another instance or two on this law of

motion. Put a basin of water into your little sister's waggon, and when the water is perfectly still, move the waggon; and the water, resisting the motion of the vessel, will at first rise up in the direction contrary to that in which the vessel moves. If, when the motion of the vessel is communicated to the water, you suddenly stop the waggon, the water, in endeavouring to continue the state of motion, rises up on the opposite side.

In like manner, if, while you are sitting quietly on your horse, the animal starts forward, you will be in danger of falling off backward; but if while you are galloping along, the animal stops on a sudden, you will be liable to be thrown forward.

C. This I know by experience, but I was not aware of the reason of it till to-day.

F. You were wondering the other day how the rider at the circus, while his horse was in full gallop, could jump over a rope and fall *exactly* on the horse's back; but you will now see that as he already has the onward circular motion, the only motion he had to give himself was an *upward* motion in order to clear the rope; the onward motion carried him to his place again on the saddle.

E. Now I see why the floor of the railway carriage, although going 40 miles an hour, did not run away from my watch the other day, and let it fall on the cushion.

F. Yes, and you now see that, when some obstacle suddenly stops a train, the passengers are *carried onward*, and hurled against the front side of the carriages.

One of the first, and not least important uses of the principles of natural philosophy, is, that they may be applied to, and will explain, many of the common concerns of life.

We now come to the *second* law of motion, which is:—"*that the change of motion is proportional to the force impressed, and in the direction of that force.*"

C. There is no difficulty in this; for if, while my cricket-ball is rolling along, after Henry has struck it, I strike it again, it goes on with increased velocity, and that in proportion to the strength which I exert on the occasion; whereas, if while it is rolling, I strike it back again, or give it a side blow, I change the direction of its course.

F. In the same way, gravity, and the resistance of the atmosphere, change the direction of a cannon-ball from its course in a straight line, and bring it to the ground; and the ball goes to a greater or less distance in proportion to the quantity of power used.

The *third* law of motion is:—"*that to every action of one body upon another, there is an equal and contrary re-action.*" If I strike

this table, I communicate to it (which you perceive by the shaking of the glasses) the motion of my hand: and the table reacts against my hand, just as much as my hand acts against the table.

If you press with your finger one scale of a balance, to keep it in equilibrio with a pound weight in the other scale, you will perceive that the scale pressed by the finger acts against it with a force equal to a pound, with which the other scale endeavours to descend.

In all cases the quantity of motion gained by one body is always equal to that lost by the other in the same direction. Thus, if a ball in motion strike another at rest, the motion communicated to the latter will be taken from the former, and the velocity of the former will be proportionally diminished.

A horse drawing a heavy load is as much drawn back by the load as he draws it forward.

E. I do not comprehend how the cart draws the horse.

F. But the progress of the horse is impeded by the load, which is the same thing; for the force which the horse exerts would carry him to a greater distance in the same time, were he freed from the incumbrance of the load, and therefore, as much as his progress falls short of that distance, so much is he, in effect, drawn back by the reaction of the loaded cart.

Again, if you and your brother were in a boat, and if, by means of a rope, you were to attempt to draw another to you, the boat in which you were would be as much pulled toward the other boat as that would be moved to you; and if the weights of the two boats were equal, they would meet in a point half way between the two.

If you strike a glass bottle with an iron hammer, the blow will be received by the hammer and the glass; and it is immaterial whether the hammer be moved against the bottle at rest, or the bottle be moved against the hammer at rest, yet the bottle will be broken, though the hammer be not injured, because the same blow which is sufficient to break glass is not sufficient to break or injure a mass of iron.

E. But how was it, papa, that, when Edward carelessly directed his gun yesterday toward the greenhouse, the bullet passed through the glass, making a hole, but not cracking the glass?

F. Because a certain amount of time is necessary for a force to propagate itself through a body; and the bullet passed so quickly that the particles of glass, against which it struck, were *carried away* before the motion imparted to them had been propagated to the rest of the glass. Had he *thrown* the bullet with

his hand, the motion would have been sufficiently slow to allow the force to be communicated, and the glass would have been broken.

From this law of motion you may learn in what manner a bird, by the stroke of its wings, is able to support the weight of its body.

C. Pray explain this, papa.

F. If the force with which it strikes the air below it is *equal* to the weight of its body, then the reaction of the air upwards is likewise equal to it; and the bird, being acted upon by two *equal* forces in contrary directions, will rest between them. If the force of the stroke is *greater* than its weight, the bird will rise with the *difference* of these two forces; and if the stroke be *less* than its weight, then it will sink with the difference.

CONVERSATION XII.

On the Laws of Motion.

C. I am prepared to believe that those laws of motion which you explained yesterday are of great importance in natural philosophy.

F. Indeed they are, and should be carefully committed to memory. They were assumed by Sir Isaac Newton as the fundamental principles of mechanics, and you will find them at the head of most books written on these subjects. From these also we are naturally led to some other branches of science, which, though we can but slightly mention them, should not be wholly neglected. They are, in fact, but corollaries to the laws of motion.

E. What is a corollary, papa?

F. It is nothing more than some truth clearly deducible from some other truth before demonstrated or admitted. Thus, by the *first* law of motion, *every body must endeavour to continue in the state into which it is put, whether it be of rest, or uniform motion in a straight line:* from which it follows, as a corollary, "that when we see a body move in a curve line, it must be acted upon by at least two forces."

C. When I whirl a stone round in a sling, what are the two forces which act upon the stone?

F. There is the force by which, if you let go the string, the stone will fly off in a right line; and there is the force of the hand, which keeps it in a circular motion.

E. Are there any of these circular motions in nature?

F. The moon and all the planets move by analogous laws — to

take the moon as an instance. It has a constant tendency to the earth, by the attraction of gravitation, and it has also a tendency to proceed in a right line, by that projectile force impressed upon it by the Creator, in the same manner as the stone flies from your hand; now, by the joint action of these two forces, it has a circular motion.

E. And what would be the consequence, supposing the projectile force to cease?

F. The moon must fall to the earth; and if the force of gravity were to cease acting upon the moon, it would fly off into infinite space. Now the projectile force, when applied to the planets, is called the *centrifugal* force, as having a tendency to recede or fly from the centre; and the other is termed the *centripetal* force, from its tendency to some point as a centre.

When Mary twirls the mop, you see the threads all arrange themselves like rays from a centre; but the drops of water all fly off perpendicular to the rays: the position of the threads is the direction of the *centripetal* force, that of the drops, of the *centrifugal.*

C. And all this in consequence of the inactivity of matter by which bodies have a tendency to continue in the same state they are in, whether of rest or motion?

F. You are right; and this principle, which Sir Isaac Newton assumed to be in all bodies, he called their *vis inertiæ*, to which we have before referred.

C. A few mornings ago you showed us that the attraction of the earth upon the moon * is 3600 times less than it is upon heavy bodies near the earth's surface. Now, as this attraction is measured by the space fallen through in a given time, I have endeavoured to calculate the space which the moon would fall through in a minute, were the projectile force to cease.

F. Well, and how have you brought it out?

C. A body falls here 16 feet in the first second, consequently in a minute, or 60 seconds, it would fall 60 times 60 feet, that is 3600 feet, which is to be multiplied by 16; and as the moon would fall through 3600 times less space in a given time than a body here, it would fall only 16 feet in the first *minute.*

F. Your calculation is accurate. I will recall to your mind the *second* law, by which it appears, *that every motion or change of motion produced in a body, must be proportional to, and in the direction of, the force impressed.* Therefore, if a moving body receives an impulse in the direction of its motion, its velocity will be increased; if in the contrary direction, its velocity will be diminished; but if the force be impressed in a direction

* See Conversation IV.

oblique to that in which it moves, then its direction will be between that of its former motion, and that of the new force impressed.

C. This I know from the observations I have made with my cricket-ball.

F. By this second law of motion, you will easily understand that if a body at rest receive two impulses, at the same time, from forces whose directions do not coincide, it will, by their joint action, be made to move in a line that lies between the direction of the forces impressed.

E. Have you any machine in order to prove this satisfactorily to the senses?

F. There are many such, invented by different persons, descriptions of which you will hereafter find in various books on these subjects. But it is easily understood by a figure. If on the ball A a force be impressed sufficient to make it move with an uniform velocity to the point B, in a second of time; and if another force be also simultaneously impressed on the ball which alone would make it move to the point C, in the same time; the ball, by means of the two forces, will describe the line A D, which is the diagonal of a figure, whose sides are A C and A B.

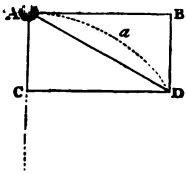


Fig. 14.

C. How then is motion produced in the *direction of the force?* According to the second law, it ought to be, in one case, in the direction A C, and, in the other, in that of A B, whereas it is in that of A D.

F. Examine the figure a little attentively, carrying this in your mind, that for a body to move in the *same direction*, it is *not* necessary that it should move in the *same straight line;* but that it is sufficient to move *either* in that line, or in any one parallel to it.

C. I perceive then that the ball, when arrived at D, has moved in the direction A C, because B D is parallel to A C; and also in the direction A B, because C D is parallel to it.

F. And in no other possible situation but at the point D, could this experiment be conformable to the second law of motion.

You will not forget that, if a body move in a curve, the *continued* action of external force must be inferred; if that action were to cease at any point, the body would continue its motion in a straight line, touching the curvilinear path in that point.

CONVERSATION XIII.

On the Laws of Motion.

F. If you reflect a little upon what we said yesterday on the second law of motion, you will readily deduce the following corollaries, referring, as you go along, to the last diagram.

1. That, if the forces be equal, and act at right angles to one another, the line described by the ball will be the diagonal of a *square*. But in all other cases it will be the diagonal of a parallelogram of some kind.

2. By varying the angle and the forces, you vary the form of your parallelogram.

C. Yes, papa; and I see another consequence, *viz.* that the motions of two forces acting conjointly in this way are not so great as when they act separately.

F. That is true; and you are led to the conclusion, I suppose, from the recollection, that in every triangle any two sides taken together are greater than the remaining side; and therefore you infer, and justly too, that the motions which the ball A must have received, had the forces been applied separately, would have been equal to A C and A B, or, which is the same thing, to A C and C D, the two sides of the triangle A D C; but by their joint action the motion is only equal to A D, the remaining side of the triangle.

Hence, then, you will remember, that in the *composition*, or adding together of forces (as this is called), motion is always lost: and in the *resolution* of any one force, as A D, into two others, A C and A B, motion is gained.

C. Well, papa, but how is it that the heavenly bodies, the moon, for instance, which is impelled by two forces, performs her motion in a circular curve round the earth, and not in a diagonal between the direction of the projectile force and that of the attraction of gravity to the earth?

F. Because, in the case just mentioned, there was only the action of a single impulse in each direction, whereas the action of gravity on the moon is continual, and causes an accelerated motion, and hence the line is a curve.

C. Supposing, then, that A represent the moon, and A C the sixteen feet through which it would fall in a minute by the attraction of gravity towards the earth, and A B represent the projectile force acting upon it for the same time. If A B and A C acted as single impulses, the moon would in that case describe the diagonal A D; but since these forces are constantly acting, and that of gravity is an accelerating force also, instead

of the straight line A D, the moon will be drawn into the curve line A *a* D. Do I understand the matter right?

F. You do; and hence you easily comprehend how, by good instruments and calculation, the attraction of the earth upon the moon was discovered.

The *third* law of motion, viz. *that action and reaction are equal and in contrary directions*, may be illustrated by the motion communicated by the percussion of *elastic* and *non-elastic* bodies.

E. What are these, papa?

F. *Elastic* bodies are those which have a certain spring, or power of self-recovery, by which their parts, upon being pressed inwards, by percussion, return to their former state; this property is evident in a ball of wool or cotton, or in sponge compressed. *Non-elastic* bodies are those which, when one strikes another, do not rebound, but move together after the stroke.

Let two *equal* ivory balls *a* and *b* be suspended by threads; if *a* be drawn a little out of the perpendicular, and be let fall upon *b*, it will lose its motion by communicating it to *b*, which will be driven to a distance *c*, equal to that through which *a* fell; and hence it appears that the reaction of *b* was equal to the action of *a* upon it.

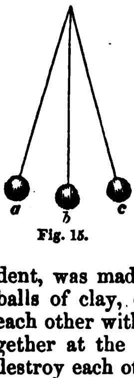


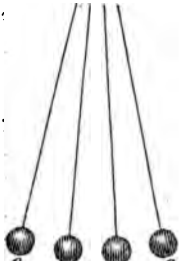
Fig. 15.

E. But do the parts of the ivory balls yield by the stroke, or, as you call it, by percussion?

F. They do; for if I lay a little paint on *a*, and let it *touch* *b*, it will make but a very small speck upon it: but if it *fall* upon *b*, the speck will be much larger; which proves that the balls are elastic, and that a little hollow, or dent, was made in each by collision. If now two equal soft balls of clay, or glazier's putty, which are non-elastic, meet each other with equal velocities, they would stop and stick together at the place of their meeting, as their mutual actions destroy each other.

C. I have sometimes shot my white alley against another marble so plumply, that the marble has gone off as swiftly as the alley approached it, but the alley remained motionless in the place of the marble. Are marbles, therefore, as well as ivory, elastic?

F. They are; but neither of them *perfectly* elastic.— If three elastic balls, *a*, *b*, *c*, be hung from the adjoining centres, and *c* be drawn a little out of the perpendicular, and let fall upon *b*, then will *c* and *b* become stationary, and *a* will be


o a b c
Fig. 16.

driven to *o*, the distance through which *c* fell upon *b*.

If you hang any number of balls, as six, eight, &c., so as to touch each other, and if you draw the outside one away to a little distance, and then let it fall upon the others, the ball on the opposite side will be driven off, while the rest remain stationary, so equal is the action and reaction of the stationary balls divided among them. In the same manner, if two are drawn aside, and suffered to fall on the rest, the opposite two will fly off, and the others remain stationary.

There is one other circumstance depending upon the action and reaction of bodies, and also upon the *vis inertiæ* of matter, worth noticing; by some authors you will find it largely treated upon.

If I strike a blacksmith's anvil with a hammer, action and reaction being equal, the anvil strikes the hammer as forcibly as the hammer strikes the anvil.

If the anvil be large enough, I might lay it on my breast, and suffer you to strike it with a sledge hammer with all your strength, without pain or risk; for the *vis inertiæ* of the anvil resists the force of the blow, without acquiring any perceptible velocity. But if the anvil were but a pound or two in weight, your blow would probably kill me.

E. Is it owing to this principle, that when a cannon on wheels is fired, it runs backward?

F. It is; for the action of the powder produces as great a quantity of momentum in the gun, as in the ball, but their motions are contrary; the ball moves forward and the cannon backward, and the cannon slower in proportion as its mass and weight are greater.

CONVERSATION XIV.

On the Mechanical Powers.

C. Will you now, papa, explain the mechanical powers?

F. I will, and I hope you have not forgotten what the *momentum* of a body is?

C. No; it is the force of a moving body, which force is estimated by the weight, multiplied into its velocity.

E. Then a small body may have an equal momentum with one much larger?

C. Yes, provided the smaller body moves as much more swiftly than the larger one, as the weight of the latter is greater than that of the former.

F. What do you mean when you say that one body moves more swiftly, or has a greater velocity than another?

C. That it passes over a greater space in the same time. Your watch will explain my meaning: the minute-hand travels round the dial-plate in an hour, but the hour-hand takes twelve hours to perform its course, consequently the velocity of the minute-hand is twelve times greater than that of the hour-hand; because, in the same time, *viz*. twelve hours, it travels twelve times the space that is gone through by the hour-hand.

F. But this can be only true on the supposition that the two circles are equal. In my watch, the minute-hand is longer than the other, and, consequently, the circle described by it is larger than that described by the hour-hand.

C. I see at once, that my reasoning holds good only in the case where the hands are equal.

F. There is, however, a particular point of the longer hand, of which it may be said, with the strictest truth, that it has exactly twelve times the velocity of the extremity of the shorter.

C. That is the point, at which, if the remainder were cut off, the two hands would be equal. And, in fact, every different point of the hand describes different spaces in the same time.

F. The little pivot on which the two hands seem to move (for they are really moved by different pivots, one within another) may be called the *centre of motion*, which is a fixed point; and the longer the hand is, the greater is the space described.

C. The extremities of the vanes of a windmill, when they are going very fast, are scarcely distinguishable, though the separate parts, nearer the mill, are easily discerned; this is owing to the velocity of the extremities being so much greater than that of the other parts.

E. Did not the swiftness of the round-abouts, which we saw at the fair, depend on the same principle, *viz*. the length of the poles upon which the seats were fixed?

F. Yes; the greater the distance at which these seats were placed from the centre of motion, the greater was the space which the little boys and girls travelled for their half-penny.

E. Then those in the second row had a shorter ride for their money than those at the end of the poles?

F. Yes, shorter as to space, but the same as to time. In the

same way, when you and Charles go round the gravel walk for half an hour's exercise, if he run while you walk, he will perhaps have gone six or eight times round in the same time that you have been but three or four times round: now, as to time, your exercise has been equal, but he may have passed over double the space in the same time.

C. How does this apply to the explanation of the mechanical powers?

F. You will find the application very easy:—without clear ideas of what is meant by *time* and *space*, you cannot comprehend the principles of mechanics.

There are six mechanical powers: the lever, the wheel and axis, the pulley, the inclined plane, the wedge, and the screw.

E. Why are they called mechanical powers?

F. Because, by their means, we are enabled *mechanically* to raise weights, move heavy bodies, and overcome resistances, which, without their assistance, could not be done.

C. But is there no limit to the assistance gained by these powers? for I remember reading of Archimedes, who said, that with a place for his fulcrum he could move the earth itself.

F. Human power, with all the assistance which art can give, is very soon limited, and upon this principle, *that what we gain in power, we lose in time.* That is, if, by your own unassisted strength, you are able to raise fifty pounds to a certain distance in one minute, and if, by the help of machinery, you wish to raise 500 pounds to the same height, you will require ten minutes to perform it in: thus you increase your power tenfold, but it is at the expense of time. Or, in other words, you are enabled to do that with one effort in ten minutes, which you could have done in ten separate efforts in the same time.

E. Then it appears that besides a place for his fulcrum, Archimedes would have required time; yes, and a great deal of time, would he not?

F. Yes, dear; I once made a calculation of the number of years he would require to move the earth an inch: scores and scores of figures were necessary to express the time.

E. Then there is no real gain of force acquired by the mechanical powers?

F. Though there be not any actual increase of force gained by these powers, yet the advantages which men derive from them are inestimable. If there are several small weights, manageable by human strength, to be raised to a certain height, it may be fully as convenient to elevate them one by one, as to take the advantage of the mechanical powers in raising them all at once. Because, as we have shown, the same time will be

necessary in both cases. But suppose you have a large block of stone of a ton weight to carry away, or a weight still greater, what is to be done?

E. I did not think of that.

F. Bodies of this kind cannot be separated into parts proportionable to the human strength without immense labour, nor, perhaps, without rendering them unfit for those purposes to which they are to be applied. Hence, then, you perceive the great importance of the mechanical powers, and of their combinations, by the use of which a man is able with ease to manage a weight many times greater than himself.

C. I have, indeed, seen a few men, by means of pulleys, and apparently with no very great exertion, raise an enormous oak tree into a timber-carriage, in order to convey it to the dock-yard.

F. A very excellent instance; for if the tree had been cut into such pieces as could have been managed by the natural strength of these men, it would not have been worth carrying to Deptford or Chatham for the purpose of ship-building.

E. But what is a fulcrum?

F. It is a *fixed point*, or prop, round which the other parts of a machine move.

C. Is the pivot upon which the hands of your watch move a fulcrum then?

F. It is; and you remember we called it also the centre of motion; the rivet of these scissors is also a fulcrum, and also the centre of motion.

E. Is that a fixed prop or point?

F. Certainly it is a fixed point, as it regards the two parts of the scissors; for that always remains in the same position, while the other parts move about. Take the poker and stir the fire: —now that part of the bar on which the poker rests is a fulcrum, for the poker moves upon it as a centre.

CONVERSATION XV.

Of the Lever.

F. We will now consider the *Lever*, which is generally called the first mechanical power.

The *lever* is an inflexible bar of wood, iron, &c., which serves to raise weights, while it is supported at the point by a prop or fulcrum, on which, as the centre of motion, all the other parts turn. A B will represent a lever, and the point C the fulcrum or centre of motion. Now it is evident, if the lever turn on its

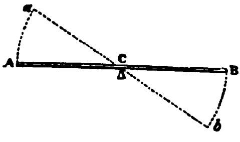


Fig. 17.

centre of motion C, so that A comes into the position *a*, B at the same time must come into the position *b*. If both the arms of the lever be equal, that is, if A C is equal to B C, there is no advantage gained by it; for they pass over equal spaces in the same time; and, according to the fundamental principles already laid down (p. 38), "as advantage or power is gained, time must be lost;" therefore, no time being lost by a lever of this kind, there can be no power gained.

C. Why then is it called a mechanical power?

E. Strictly speaking, perhaps it ought not to be numbered as one. But it is usually reckoned among them, having the fulcrum between the weight and the power, which is the distinguishing property of levers of the first kind. And, when the fulcrum is exactly the middle point between the weight and power, it is the common balance: to which, if scales be suspended at A and B, it is fitted for weighing all sorts of commodities.

E. You say it is a lever of the *first* kind; are there several sorts of levers?

F. There are three sorts; some persons reckon four; the fourth, however, is but a bended one of the first kind. A lever of the *first* kind has the fulcrum between the weight and power.

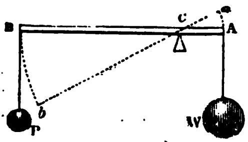


Fig. 18.

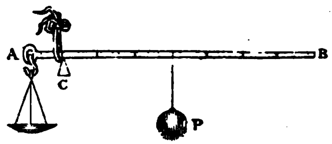


Fig. 19.

The *second* kind of lever has the fulcrum at one end, the power at the other, and the weight between them.

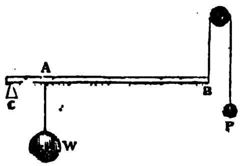


Fig. 20.

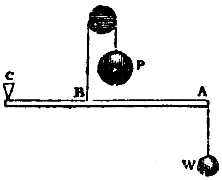


Fig. 21.

In the *third* kind the power is between the fulcrum and the weight.

Let us take the lever of the first kind (fig. 18.) which, if it be moved into the position *a b*, by turning on its fulcrum, C, it is evident, that while A has travelled over the short space A *a*, B has travelled over the greater space B *b*, which spaces are to one another exactly in proportion to the length of the arms A C and B C. If you now apply your hand first to the point A, and afterwards to B, in order to move the lever into the position *a b*, using the same velocity in both cases, you will find, that the time spent in moving the lever when the hand is at B, will be as much greater than that spent when the hand is at A, as the arm B C is longer than the arm A C; but then the exertion required will, in the same proportion, be less at B than at A.

C. The arm B C appears to be four times the length of A C.

F. Then it is a lever which gains power in proportion of four to one. That is, a single pound weight applied to the end of the arm B C, as at P, will balance four pounds suspended at A, as W.

C. I have seen workmen move large pieces of timber to very small distances, by means of a long bar of wood or iron; is that a lever?

F. It is; they force one end of the bar under the timber, and then place a block of wood, stone, &c. beneath, and as near the same end of the lever as possible, for a fulcrum, applying their own strength to the other; and power is gained in proportion as the distance from the fulcrum to the part where the men apply their strength, is greater than the distance from the fulcrum to that end under the timber. Handspikes are levers of this kind, and by these the heaviest cannon are moved.

C. It must be very considerable, for I have seen two or three men move a tree, in this way, of several tons' weight, I should think.

F. That is not difficult; for supposing a lever to gain the advantage of twenty to one, and a man by his natural strength is able to move but a hundred-weight, he will find that by a lever of this sort he can move twenty hundred-weight, or a ton; but for single exertions, a strong man can put forth much greater power than is sufficient to move a hundred-weight; and levers are also frequently used, the advantage gained by which is still more considerable than twenty to one.

There is another method, by means of a lever of the first kind, of moving, and even of pulling trees up by their roots. A strong scantling of timber, fixed perpendicularly to the axle of a pair of cart wheels, is strapped firmly to the tree; and when the lateral

roots are cut by digging a trench round it, the tap root or roots are easily torn up by a team of two or three horses; for the tree itself becomes the lever, and the axle of the wheels its fulcrum.

C. I think you said, the other day, that the common steelyard, made use of by the butcher, is a lever?

F. I did; the short arm A C (see figs. 18 and 19.) is, by an increase in size, made to balance the longer one B C, and from C, the centre of motion, the divisions must commence. Now if B C be divided into as many parts as it will contain, each equal to A C, a single weight, as a pound, P, will serve for weighing any thing as heavy as itself, or as many times heavier as there are divisions in the arm C. If the weight P be placed at the division 1, in the arm B C, it will balance one pound in the scale at A; if it be removed to 3, 5, or 7, it will balance 3, 5, or 7 pounds in the scale; for these divisions being respectively 3, 5, or 7 times the distance from the centre of motion, C, that A is, it becomes a lever, which gains advantage at those points, in the proportion of 3, 5, 7. If now the intervals between the divisions on the longer arm be subdivided into halves, quarters, &c., any weight may be accurately ascertained, to halves, quarters of pounds, &c.

CONVERSATION XVI.

Of the Lever.

E. What advantage has the steelyard, which you described in our last Conversation, over a pair of scales?

F. It may be much more readily removed from place to place; it requires no apparatus, and only a single weight for all the purposes to which it can be applied. Sometimes the arms are not of equal weight; in that case the weight P must be moved along the arm B C, till it exactly balance the other arm without a weight; and in that point a notch must be made, marking over it a cipher, 0, from whence the divisions must commence.

C. Is not great accuracy required in the manufacture of instruments of this kind?

F. Yes; of such importance is it to the public that there should be no error or fraud by means of false weights, or false balances, that it is the business of certain public officers to examine at stated seasons the weights, measures, &c., of every shopkeeper in the land. Yet it is to be feared, that, after all precautions, much fraud is practised upon the unsuspecting.

E. I one day last summer bought, as I supposed, a pound

of cherries at the door; but Charles thinking there was not a pound, we tried them in our scales, and found but twelve ounces, or three quarters, instead of a pound, and yet the scale went down as if the man had given me full weight. How was that managed?

F. It might be done many ways: by short weights; or by the scale in which the fruit was put being heavier than the other;—but fraud may be practised with honest weights and scales by making the arm of the balance on which the weight hangs shorter than the other, for then a pound weight will be balanced by less fruit than a pound; this was probably the method, by which you were cheated.

E. By what method could I have discovered this cheat?

F. The scales when empty are exactly balanced, but when loaded, though still in equilibrio, the weights are unequal, and the deceit is instantly discovered by changing the weights to the contrary scales. I will give you a rule to find the true weight of any body by such a false balance; the reason of the rule you will understand hereafter: "*Find the weights of the body by both scales, multiply them together, and then find the square root of the product, which is the true weight.*"

C. Let me see if I understand the rule: suppose a body weigh 16 ounces in one scale, and in the other 12 ounces and a quarter, I multiply 16 by 12 and a quarter, and I get the product, 196, the square root of which is 14: for 14 multiplied into itself gives 196; therefore the true weight of the body is 14 ounces.

F. That is just what I meant; but let me proceed.—To the lever of the first kind may be referred many common instruments, such as scissors, pincers, snuffers, &c., which are made by two levers, acting contrary to one another.

E. The rivet is the fulcrum, or centre of motion, the hand the power used, and whatever is to be cut is the resistance to be overcome.

C. A poker stirring the fire is also, as you hinted yesterday, a lever; for the bar is the fulcrum, the hand the power, and the coals the resistance to be overcome.

F. We now proceed to levers of the second kind, in which the fulcrum C (fig. 20.) is at one end, the power P applied at the other B, and the weight to be raised W, somewhere between the fulcrum and the power.

C. And how is the advantage gained to be estimated in this lever?

F. By looking at the figure, you will find that power or advantage is gained in proportion as the distance B, the point at which

the power P acts, is greater than the distance of the weight W from the fulcrum.

C. Then if the weight hang at one inch from the fulcrum, and the power acts at five inches from it, the power gained is five to one, or one pound at P will balance five at W?

F. It will; for you perceive that the power passes over five times as great a space as the weight, or while the point A in the lever moves over one inch, the point B will move over five inches.

E. What things in common use are to be referred to the lever of the second kind?

F. The most common and useful of all things: every door, for instance, which turns on hinges is a lever of this sort. The hinges may be considered as the fulcrum or centre of motion, the whole door is the weight to be moved, and the power is applied to that side on which the lock is usually fixed.

E. Now I see the reason why there is considerable difficulty in pushing open a heavy door, if the hand is applied to the part next the hinges, although it may he opened with the greatest ease in the usual method.

C. This sofa, with my sister upon it, represents a lever of the second kind?

F. Certainly; if, while she is sitting upon it in the middle, you raise one end while the other remains fixed as a prop or fulcrum. To this kind of lever may be also reduced nut-crackers; oars; rudders of ships; those cutting-knives which have one end fixed in a block, such as are used for cutting chaff, drugs, wood for pattens, &c.

E. I do not see how oars and rudders are levers of this sort.

F. The boat is the weight to be moved, the water is the fulcrum, and the waterman at the handle the power. The masts of ships are also levers of the second kind, for the bottom of the vessel is the fulcrum, the ship the weight, and the wind acting against the sail is the moving power.

The knowledge of this principle may be useful in many situations and circumstances of life:—if two men unequal in strength have a heavy burden to carry on a pole between them, the ability of each may be consulted by placing the burden as much nearer to the stronger man as his strength is greater than that of his partner.

E. Which would you call the prop in this case?

F. The stronger man, for the weight is nearest to him, and then the weaker must be considered as the power. Again, two horses may be so yoked to a carriage that each shall draw a part proportioned to his strength, by dividing the beam in such

a manner, that the point of traction, or drawing, may be as much nearer to the stronger horse than to the weaker, as the strength of the former exceeds that of the latter.

The principle of the wheelbarrow may be referred to a lever of the second kind. The fulcrum C may be considered as the wheel, W the load, and B the place where the hands are applied; hence a man is enabled to drive or drag a much heavier load than he could carry, because his *power* at B is applied farther from the centre of motion C than the weight W.

We will now describe the third kind of lever. In this the prop or fulcrum C (as in fig. 21.) is at one end, the weight W at the other, and the power P is applied at B, somewhere between the prop and weight.

C. In this case, the weight, being farther from the centre of motion than the power, must pass through more space than it.

F. And what is the consequence of that?

C. That the power must be greater than the weight, and as much greater as the distance of the weight from the prop exceeds the distance of the power from it; that is, to balance a weight of three pounds at A, there will require the exertion of a power P, acting at B, equal to five pounds.

F. Since then a lever of this kind is a disadvantage to the moving power, it is but seldom used, and only in cases of necessity; such as in that of a ladder, which, being fixed at one end against a wall or other obstacle, is, by the strength of a man's arm, raised into a perpendicular or vertical position. But the most important application of this third kind of lever is manifest in the structure of the limbs of animals, particularly in those of man: to take the arm as an instance; when we lift a weight by the hand, it is effected by means of muscles coming from the shoulder-blade, and terminating about one-tenth as far below the elbow as the hand is: now the elbow being the centre of motion round which the lower parts of the arm turn, according to the principle just laid down, the muscles must exert a force ten times as great as the weight that is raised. At first view this may appear a disadvantage, but what is lost in power is gained in velocity, and thus the human figure is better adapted to the various functions it has to perform.

CONVERSATION XVII.

Of the Wheel and Axle.

F. Well, Emma, do you understand the principle of the lever, which we discussed so much at large yesterday?

E. The lever gains advantage in proportion to the space passed through by the acting power; that is, if the weight to be raised be at the distance of one inch from the fulcrum, and the power is applied nine inches distant from it, then it is a lever which gains advantage as 9 to 1, because the space passed through by the *power* is nine times greater than that passed through by the weight; and, therefore, what is lost in time by passing through a greater space, is gained in power.

F. You recollect also what the different kinds of levers are, I hope.

E. I shall never see the fire stirred without thinking of a simple lever of the first kind; my scissors will frequently remind me of a combination of two levers of the same sort. The opening and shutting of the door will prevent me from forgetting the nature of the lever of the second kind: and I am sure, that I shall never see a workman raise a ladder against a house without recollecting the third sort of lever. Besides, I believe a pair of tongs is a lever of this kind.

F. You are right; for the fulcrum is at the joint, and the power is applied between that and the parts used in taking up coals, &c. — Can you, Charles, tell us how the principle of *momentum* applies to the lever?

C. The *momentum* of a body is estimated by its weight, multiplied into its velocity, and the velocity must be calculated by the space passed through in a given time. Now, if I examine the lever (see figs. 17. and 18.) and consider it as an inflexible bar, turning on a centre of motion, it is evident that the same time is used for the motion both of the weight and the power, but the spaces passed over are very different; that which the power passes through being as much greater than that passed by the weight, as the length of the distance of the power from the prop is greater than the distance of the weight from the prop; and the velocities, being as the spaces passed in the same time, must be greater in the same proportion. Consequently the velocity of P, the power, multiplied into its weight, will be equal to the smaller velocity of W, multiplied into its weight, and thus, their momenta being equal, they will balance one another.

F. This applies to the first and second kind of lever; what do you say to the third?

C. In the third, the velocity of the power P, being less than that of the weight W, it is evident, in order that their momenta may be equal, that the weight acting at P must be as much greater than that of W, as AC is less than BC, and then they will be in equilibrio.

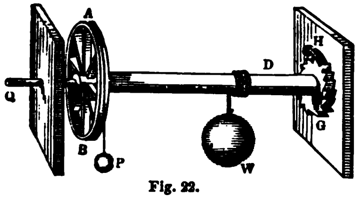


Fig. 22.

F. The second mechanical power is the *wheel and axle*, which gains power in proportion as the circumference of the wheel is greater than that of the axis; this machine may be referred to the principle of the lever. A B is the wheel, Q D its axis: and if the circumference of the wheel be eight times as great as that of the axis, then a single pound, P, will balance a weight, W, of eight pounds.

C. Is it by an instrument of this kind that water is drawn from those deep wells so common in many parts of the country?

F. It is; but as in most cases of this kind only a single bucket is raised at once, there requires but little power in the operation, and therefore instead of a large wheel, as A B, an iron handle fixed at Q is made use of, which, you know, by its circular motion, answers the purpose of a wheel.

C. I once raised some water by a machine of this kind, and I found that as the bucket ascended nearer the top the difficulty increased.

F. That must always be the case, where the wells are so deep as to cause, in the ascent, the rope to coil more than once the length of the axis, because the advantage gained is in proportion as the circumference of the wheel is greater than that of the axis; so that if the circumference of the wheel be 12 times greater than that of the axis, one pound applied at the former will balance 12 hanging at the latter; but by the coiling of the rope round the axis, the *difference* between the circumference of the wheel and that of the axis continually diminishes; consequently the advantage gained is less every time a new coil of rope is wound on the whole length of the axis: this explains why the difficulty of drawing the water or any other weight increases as it ascends nearer the top. But in this case, as in that of the mere lever, what you lost in power, you gained in time; for, with the same velocity of the handle, the bucket rose *faster* as it arrived at the top of its course.

C. Then by diminishing the axis, or by increasing the length of the handle, advantage is gained?

F. Yes, by either of those methods we may gain power; but it is very evident that the axis cannot be diminished beyond a certain limit, without rendering it too weak to sustain the weight; nor can the handle be managed if it be constructed on a scale much larger than what is commonly used.

C. We must then have recourse to the wheel with spikes standing out of it at certain distances from each other to serve as levers.

F. You may by this means increase your power according to your wish, but it must be at the expense of time, for you know that a simple handle may be turned several times while you are pulling the wheel round once.

To the principle of the *wheel and axle* may be referred the capstan, windlass, and all those numerous kinds of cranes, which are to be seen at the different wharfs on the banks of the Thames.

C. I have seen a crane, which consists of a wheel large enough for a man to walk in.

F. In this the weight of the man, or men (for there are sometimes two or three), is the moving power; for as the man steps forwards, the part upon which he treads becomes the heaviest, and consequently descends till it be the lowest. On the same principle, you may see at the door of many bird-cage makers, a bird, by its weight, give a wicker cage a circular motion; now if there were a small weight suspended to the axis of the cage, the bird by its motion would draw it up, for as it hops from the bottom bar to the next, its *momentum* causes that to descend, and thus the operation is performed, both with regard to the cage, and to those large cranes which you have seen.

The wheel of the tread-mill is analogous to this; differing only in the men being on instead of within the wheel: the long wheel is furnished with boards, and the men step up, and up, and up, and so press the wheel round.

E. Is there no danger if the man happen to slip?

F. If the weight be very great, a slip with the foot may be attended with very dangerous consequences. To prevent which, there is generally fixed at one end of the axle a little wheel, G (see fig. 22.), called a rachet-wheel; with a catch, H, to fall into its teeth; this will at any time support the weight in case of an accident. Sometimes, instead of men walking in the great wheel, cogs are set round it on the outside, and a small trundle wheel made to work in the cogs, and to be turned by a winch.

C. Are there not other sorts of cranes, in which all danger is avoided?

F. The crane is a machine of such importance to the commercial concerns of this country, that new inventions of it are continually offered to the public: I will, when we go to the library, show you in the volumes of the "Transactions of the Society for the Encouragement of Arts," &c., engravings of safe and excellent cranes.

C. You said that this mechanical power might be considered as a lever of the first kind.

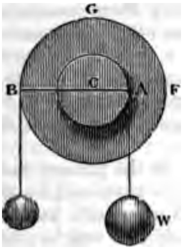


Fig. 23.

F. I did; and if you conceive the wheel and axis to be cut through the middle in the direction A B, F G B will represent a section of it. A B is a lever, whose centre of motion is C; the weight W, sustained by the rope A W, is applied at the distance C A, the radius of the axis; and the power P, acting in the direction B P, is applied at the distance C B, the radius of the wheel; therefore, according to the principle of the lever, the power will balance the weight when it is as much less than the weight as the distance C B is greater than the distance of the weight A C.

CONVERSATION XVIII.

Of the Pulley.

F. The third mechanical power, the *pulley*, may be likewise explained on the principle of the lever. The line A B may be conceived to be a lever, whose arms, A C and B C, are equal, and C the fulcrum, or centre of motion. If now two equal weights, W and P, be hung on the cord passing over the pulley, they will balance one another, and the fulcrum will sustain both.

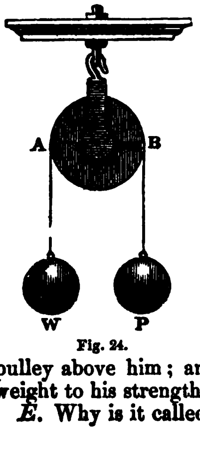


Fig. 24.

C. Does this pulley then, like the common balance, give no advantage?

F. From the single *fixed* pulley no mechanical advantage is derived; it is, nevertheless, of great importance in changing the direction of a power, and is very much used in buildings for drawing up small weights, it being much easier for a man to raise such burdens by means of a single pulley, than to carry them up a long ladder; especially as he has the advantage of placing the pulley above him; and by pulling downwards adding his own weight to his strength.

E. Why is it called a mechanical power?

F. Though a single fixed pulley gives no advantage, yet when it is not fixed, or when two or more are combined into what is called a system of pulleys, they then possess all the properties of the other mechanical powers. Thus in C D B, C is the fulcrum; therefore a power P acting at B, will sustain a double weight W, acting at A, for B C is double the distance of A C from the fulcrum.

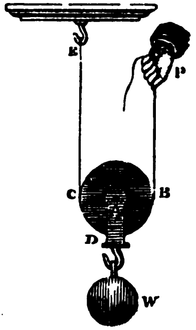


Fig. 25.

Again, it is evident, in the present case, that the whole weight is sustained by the cord E D P, and whatever sustains half the cord, sustains also half the weight; but one half is sustained by the fixed hook E, consequently the power at P has only the other half to sustain, or, in other words, any given power at P will keep in equilibrio a double weight at W.

C. Is the velocity of P double that of W?

F. Undoubtedly; if you compare the space passed through by the hand at P with that passed by W, you will find that the former is just double of the latter, and therefore the *momenta* of the power and weight, as in the lever, are equal; so that here again, what is gained in power is lost in time.

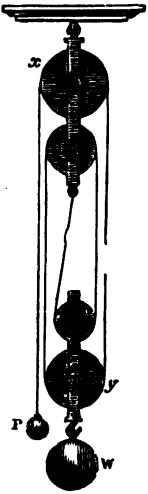


Fig. 26.

C. So that, if the weight be raised an inch or a foot, both sides of the cord must also be raised an inch, or foot, but this cannot happen without that part of the cord at P passing through two inches, or two feet of space.

F. You will now easily infer, from what has been shown of the single *movable* pulley, that, in a system of pulleys, the power gained must be estimated by doubling the number of pulleys in the lower or movable block. So that, when the fixed block *x* contains two pulleys, which only turn on their axes, and the lower block *y* contains also two pulleys, which not only turn on their axes, but also *rise* with the weight, the advantage is as four; that is, a single pound at P will sustain four at W.

C. In the present instance, also, I perceive that by raising W an inch, there are four ropes

shortened each an inch, and therefore the hand must have passed through four inches of space in raising the weight a single inch; which establishes the maxim, that what is gained in power is lost in space. But you have only talked of the power of balancing or sustaining the weight; something more must, I suppose, be added to raise it.

F. There must; considerable allowance must likewise be made for the friction of the cords, and of the pivots, or axes, on which the pulleys turn. In the mechanical powers, in general, one third of the power must be added for the loss sustained by friction, and for the imperfect manner in which machines are commonly constructed. Thus, if by *theory* you gain a power of 600, in *practice* you must reckon only upon 400. In the pulleys that we have been describing, writers have noticed three things, which take much from the general advantage and convenience of pulleys as a mechanical power. The *first* is, that the diameters of the axes bear a great proportion to their own diameters. The *second* is, that in working they are apt to rub against one another, or against the side of the block. The *third* disadvantage is the stiffness of the rope that goes over and under them.

The first two objections have been, in a great degree, removed by the concentric pulley, invented by Mr. James White; B is a solid block of brass, in which grooves are cut, in the proportion of 1, 3, 5, 7, 9, &c.; and A is another block of the same kind, whose grooves are in the proportion of 2, 4, 6, 8, 10, &c., and round these grooves a cord is passed, by which means they answer the purpose of so many distinct pulleys, every point of which moving with the velocity of the string in contact with it, the whole friction is removed to the two centres of motion of the blocks A and B: besides, it is of no small advantage, that the pulleys being all of one piece, there is no rubbing one against the other.

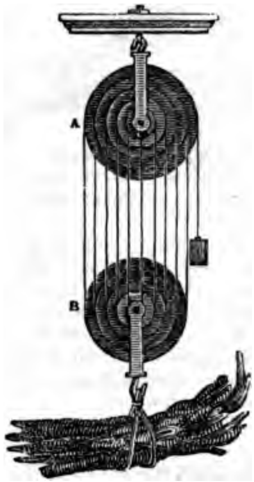


Fig. 27.

E. Do you calculate the power gained by this pulley in the same method as with the common pulleys?

F. Yes; for pulleys of every kind the rule is general; the advantage gained is found by doubling the number of the pulleys in the lower block: in that before you there are six grooves, which answer to as many distinct pulleys, and consequently the power gained is twelve, or one pound at P will balance twelve pounds at W.

CONVERSATION XIX.

Of the Inclined Plane.

F. We may now describe the inclined plane, which is the fourth mechanical power.

C. You will not be able, I think, to reduce this also to the principle of the lever.

F. No, it is a distinct principle, and some writers on these subjects reduce at once the six mechanical powers to two, *viz.* the lever and inclined plane.

E. How do you estimate the advantage gained by this mechanical power?

F. The method is very easy; for just as much as the length of the plane exceeds its perpendicular height so much is the advantage gained. Suppose A B is a plane standing on the table, and C D another plane inclined to it; if the length C D be three times greater than the perpendicular height; then the cylinder E will be supported upon the plane C D, by a weight equal to a third part of its own weight.

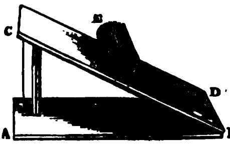


Fig. 28.

E. Could I then draw up a weight on such a plane with a third part of the strength that I must exert in lifting it up at the end?

F. Certainly you might; allowance, however, must be made for overcoming the friction; but then you perceive, as in other mechanical powers, that you will have three times the space to pass over, or that as you gain power you will lose time.

C. Now I understand the reason why two or three strong planks are laid from the street to the ground-floor warehouses, making therewith an inclined plane, when heavy packages are raised or lowered.

F. The inclined plane is chiefly used for raising heavy weights to small heights; for in warehouses situated in the upper part of buildings, cranes and pulleys are better adapted for the purpose.

C. I have sometimes amused myself by observing the differ-

ence of time which one marble has taken to roll down a smooth board, and another which has fallen by its own gravity without any support.

F. And if it were a long plank, and you took care to let both marbles drop from the hand at the same instant, I dare say you found the difference very evident.

C. I did; and now you have enabled me to account for it very satisfactorily, by showing me that as much more time is spent in raising a body along an inclined plane, than in lifting it up at the end, as that plane is longer than its perpendicular height. For I take it for granted that the rule holds in the descent as well as in the ascent.

F. If you have any doubt remaining, a few words will make everything clear. Suppose your marbles placed on a plane perfectly horizontal, as on this table, they will remain at rest wherever they are placed: now if you elevated the plane in such a manner that its height should be equal to half the length of the plane, it is evident, from what has been shown before, that the marbles would require a force equal to half their weight to sustain them in any particular position: suppose then the plane perpendicular to the table, the marbles will descend with their whole weight, for now the plane contributes in no respect to support them, consequently they would require a power equal to their whole weight to keep them from descending.

C. And the swiftness with which a body falls is to be estimated by the force with which it was acted upon?

F. Certainly; for you are now sufficiently acquainted with philosophy to know that the effect must be estimated from the cause. Suppose an inclined plane is thirty-two feet long, and its perpendicular height is sixteen feet, what time will a marble take in falling down the plane, and also in descending from the top to the earth by the force of gravity?

C. By the attraction of gravitation, a body falls sixteen feet in a second; therefore the marble will be one second in falling perpendicularly to the ground; and as the length of the plane is double its height, the marble must take two seconds to roll down it.

F. I will try you with another example. If there be a plane 64 feet perpendicular height, and 3 times 64, or 192 feet long, tell me what time a marble will take in falling to the earth by the attraction of gravity, and how long will it be in descending down the plane?

C. By the attraction of gravity it will fall in two seconds; because by multiplying the sixteen feet which it falls in the first second by the square of two seconds (the time) or four, I get

sixty-four, the height of the plane. But the plane being three times as long as it is perpendicularly high, it must be three times as many seconds in rolling down the plane as it was in descending freely by the force of gravity, that is, six seconds.*

E. Pray what common instruments are to be referred to this mechanical power, in the same way as scissors, pincers, &c., are referred to the lever?

F. Chisels, hatchets, and whatever other sharp instruments which are chamfered, or sloped down to an edge on one side only, may be referred to the principle of the inclined plane.

The principle of the inclined plane is applied in the construction of carriage-ways, for the conveyance of heavy loads up steep elevations; also in railways, &c. In crossing Westminster bridge, or in passing Holborn hill, you may have frequently observed the plan adopted by a carman to enable his horses to ascend when their load is unusually heavy; instead of going directly *forward*, he leads them gradually onward, by crossing the road from side to side: he increases the distance or time, but he is relieved from the difficulty of ascent.

CONVERSATION XX.

Of the Wedge.

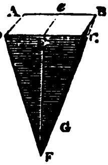


Fig. 29.

F. The next mechanical power is the *wedge*, which is made up of the two inclined planes D E F G and C E F G joined together at their bases *e* E F G; D C is the whole thickness of the wedge at its back A B C D, where the power is applied, and D F and C F are the length of its sides; now there will be an equilibrium between the power impelling the wedge downward, and the resistance of the wood or other substance acting against its sides, when the thickness D C of the wedge is to the length of the two sides, or, which is the same thing, when half the thickness D E of the wedge at its back is to the length of D F one of its sides, as the power is to the resistance.

C. This is the principle of the inclined plane.

F. It is; and notwithstanding all the disputes which the methods of calculating the advantage gained by the wedge have

* In what is above taught, no notice is taken of the effect of *rotation* upon bodies descending along an inclined plane. Considerable varieties occur in the times of actual descent, in bodies of different shape, as cylinders and spheres; and according as they are solid or hollow. This is an interesting topic of theoretical inquiry, but too intricate for perspicuous explication in a popular work like ours. The inquisitive reader may consult the more scientific treatises on Mechanics, such as those of Gregory and Bridge.

occasioned, I see no reason to depart from the opinion of those who consider the wedge as a double inclined plane.

E. I have seen people cleaving wood with wedges, but they seem to have no effect, unless great force and great velocity are also used.

F. No; the power of the attraction of cohesion, by which the parts of wood stick together, is so great as to require a considerable *momentum* to separate them. Did you observe nothing else in the operation worthy your attention?

C. Yes; I also took notice that the wood generally split a little below the place to which the wedge reached.

F. This happens in cleaving most kinds of wood, and then the advantage gained by this mechanical power must be in proportion as the length of the sides of the cleft in the wood is greater than the length of the whole back of the wedge. There are other varieties in the action of the wedge; but, at present, it is not necessary to refer to them.

E. Since you said that all instruments which sloped off on one side only were to be explained by the principle of the inclined plane; so, I suppose, that those which decline to an edge on both sides must be referred to the principle of the wedge.

F. They must; which is the case with many chisels, and almost all sorts of axes, nails, bayonets, &c.; the teeth of animals act also as wedges. A saw is a series of wedges, on which the motion impressed is oblique to the resistance.

C. Is the wedge much used as a mechanical power?

F. It is of great importance in a vast variety of cases, in which the other mechanical powers are of no avail; and this arises from the momentum of the blow, which is greater, beyond comparison, than the application of any dead weight or pressure, such as is employed in the other mechanical powers. Hence it is used in splitting wood, rocks, &c., and even the largest ship may be raised to a small height by driving a wedge below it.

E. Has it been applied to any other purposes?

F. It is used for raising the beams of a house, when the floor gives way, by reason of too great a burden having been laid upon them.

It is usual also in separating large millstones from the siliceous sand-rocks, in some parts of Derbyshire, to bore horizontal holes under them in a circle, and fill these with pegs or wedges made of dry wood, which gradually swell by the moisture of the earth, and in a day or two lift up the millstone without breaking it.

The principle of the wedge is called into action by almost

every mechanic, and in a thousand instances in which the reason of the thing is not even thought of. Builders, in raising their scaffolds, always tighten the ropes round their scaffolding poles by means of wedges driven between the cords and the poles. Chisels and knives are wedges; and so is the blade of the scissors.

CONVERSATION XXI.

Of the Screw.

F. Let us now examine the properties of the sixth and last mechanical power, the *screw;* which, however, cannot be called a simple mechanical power, since it is never used without the assistance of a lever or winch; by which it becomes a compound engine, and it is of great power in pressing bodies together, or in raising great weights. A B is the representation of one, together with the lever D F.

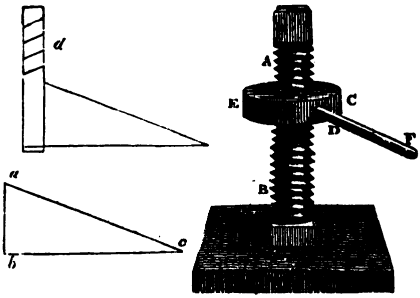


Fig. 30.

E. You said just now, papa, that all the mechanical powers were reducible either to the lever or inclined plane; how can the screw be referred to either?

F. The screw is composed of two parts, one of which, A B, is called the screw, and consists of a spiral protuberance, called the *thread*, which may be supposed to be wrapped round a cylinder; the other part C E, called the *nut*, is perforated to the dimensions of the cylinder; and in the internal cavity is also a spiral groove adapted to receive the thread. Now, if you cut a slip of writing paper in the form of an inclined plane *a b c*, and then wrap it round a cylinder of wood, *d*, you will find that it makes a spiral answering to the spiral part of the

screw; moreover, if you consider the ascent of the screw, it will be evident that it is precisely the ascent of an inclined plane.

C. By what means do you calculate the advantage gained by the screw?

F. There are, at first sight, evidently two things to be taken into consideration: the first is the distance between the threads of the screw; and the second is the length of the lever.

C. Now I comprehend pretty clearly how it is an inclined plane, and that its ascent is more or less easy as the threads of the spiral are nearer or farther distant from each other.

F. Well, then, let me examine, by a question, whether your conceptions be accurate: suppose two screws, the circumferences of whose cylinders are equal to one another; but in one the distance of the threads to be an inch apart, and that of the threads of the other only one third of an inch; what will be the difference of the advantage gained by one of the screws over the other?

C. The one whose threads are three times nearer than those of the other, must, I should think, give three times the most advantage.

F. Give me the reason for what you assert.

C. Because, from the principle of the inclined plane, I learnt that if the *height* of two planes were the same, but the length of one twice, thrice, or four times greater than that of the other, the mechanical advantage gained by the longer plane would be two, or three, or four times more than that gained by the other. Now, in the present case, the height gained in both *screws* is the same, one inch, but the space passed in that, three of whose threads go to an inch, must be three times as great as the space passed in the other; therefore, as space is passed, or time lost, just in proportion to the advantage gained, I infer that three times more advantage is gained by the screw, the threads of which are one-third of an inch apart, than by that whose threads are an inch apart.

F. Your inference is just, and naturally follows from an accurate knowledge of the principle of the inclined plane. But we have said nothing about the lever.

C. This seems hardly necessary, it being so obvious to any one, who will think a moment, that power is gained by that, as in levers of the first kind, according to the length F D from the nut.

F. Let us now calculate the advantage gained by a screw, the threads of which are half an inch distant from one another, and the lever 7 feet long.

C. I think you once told me, that if the radius of a circle were given, in order to find the circumference I must multiply the radius by 6.

F. I did; for though that is not quite enough, yet it will answer all common purposes, till you are a little more expert in the use of decimals.

C. Well, then, the circumference of the circle made by the revolution of the lever will be 7 feet, multiplied by 6, which is 42 feet, or 504 inches; but, during this revolution, the screw is only raised half an inch, therefore the space passed by the moving power will be 1008 times greater than that gone through by the weight; consequently the advantage gained is 1008, or one pound applied to the lever will balance 1008 pounds acting against the screw.

F. You perceive that it follows as a corollary from what you have been saying, that there are two methods by which you may increase the mechanical advantage of the screw.

C. I do; it may be done either by taking a long lever, or by diminishing the distance of the threads of the screw.

F. Tell me the result then, supposing the threads of the screw so fine as to stand at the distance of but one quarter of an inch asunder, and that the length of the lever were 8 instead of 7.

C. The circumference of the circle made by the lever will be 8 multiplied by 6, equal to 48 feet, or 576 inches, or 2304 quarter inches; and as the elevation of the screw is but one quarter of an inch, the space passed by the power will, therefore, be 2304 times greater than that passed by the weight, which is the advantage gained in this instance.

F. A child, then, capable of moving the lever sufficiently to overcome the friction, with the addition of a power equal to one pound, will be able to raise 2304 pounds, or something more than 20 hundred weight and a half. The strength of a powerful man would be able to do 20 or 30 times as much more.

C. But I have seen at Mr. Wilmot's paper-mills, to which I once went, six or eight men use all their strength in turning a screw, in order to press out the water of the newly made paper. The power applied in that case must have been very great indeed.

F. It was; but I dare say you are aware that it cannot be estimated by multiplying the power of one man by the number of men employed.

C. That is, because the men standing by the side of one another, the lever is shorter to every man the nearer he stands

to the screw, consequently, though he may exert the same strength, yet it is not so effectual in moving the machine, as the exertion of him who stands nearer to the extremity of the lever.

F. The true method, therefore, of calculating the power of this machine, aided by the strength of these men, would be to estimate accurately the power of each man according to his position, and then to add all these separate advantages together for the total power gained.

E. A machine of this kind is, I believe, used by bookbinders, to press the leaves of the books together before they are stitched.

F. Yes, it is found in every bookbinder's workshop, and is particularly useful where persons are desirous of having small books reduced to a still smaller size for the pocket. It is also the principal machine used for coining money, for taking off copperplate prints, and for printing in general.

C. I remember Mr. Boulton's magnificent apparatus for coining; the whole machinery is worked by a steam-engine, which rolls the copper for halfpence, works the screw presses for cutting out the circular pieces of copper, and coins both the faces and edges of the money at the same time. By this machinery, four boys, ten or twelve years old, are capable of striking 30,000 sovereigns in an hour, and the machine itself keeps an unerring account of the number of pieces struck. A higher treat an inquisitive youth cannot have than that of witnessing the process of coining, as it is carried on at the Mint, Tower hill.

E. And I have seen the cider-press in Kent, which consists of the same kind of machine.

F. It would, my dear, be an almost endless task, were we to attempt to enumerate all the purposes to which the screw is applied in the mechanical arts of life; it will perhaps, be sufficient to tell you, that wherever great pressure is required, there the power of the screw is uniformly employed.

Perhaps the most extraordinary application of the screw is in *moving houses.* In America this has been often done: a frame of timber is passed under a house — actually a brick house, and is well secured; a timber road is prepared for the house to travel along, and it is pressed onward by the application of screws: we are even told that houses have been moved in this way while the family were in them.

E. What are the screw steam-ships, in one of which cousin Fred. is about to sail to India as a midshipman?

F. At the stern, between the rudder and the keel, is a horizontal screw, at the end of a long shaft, that is kept in rotation

by a powerful steam-engine. It acts with the water somewhat as a gimlet does with a board; but, instead of entering as the gimlet does, its blades press on the water, and, as it were, drive it back, which, in practice, urges the ship forward.

The *screw-pile* is another most successful application of this mechanical power; it is employed especially for submarine foundations, for lighthouses, beacons, and other such structures. A wide-bladed iron screw is arranged at the end of wooden or other piles; and, by means of a capstan or otherwise, it is readily screwed down to the necessary depth, and can be introduced where it would be practically impossible to drive piles according to the old plans. As an instance, unsuccessful attempts had been made by the Earl of Courtown to lengthen the pier of the harbour of Courtown, on the coast of Wexford. But Mitchell's screw-piles overcame the difficulty. Iron piles, fitted with screws 2 feet in diameter, were made to penetrate 12 or 15 feet into the sand and blue clay of the harbour. The surf prevented barges or rafts being used for the workmen to turn the screw; therefore a wheel was placed on the head of each pile, over which a rope passed, and was led to a pulley on the solid pier, 150 feet distant. A gang of men here hauled at the rope, and so communicated rotatory motion to the pile. Here is an instance of the successful combination of three powers, the lever, the pulley, and the screw.

CONVERSATION XXII.

Of the Pendulum.

C. Since you last allowed us to converse with you, my dear papa, I have had an opportunity of examining a powerful crane, and other pieces of machinery; and I perceived that they are only levers and pulleys, and wheel-and-axles, with here and there, perhaps, a screw, or an inclined plane judiciously disposed; but pray, papa, what are we to do in our classifications, if we examine a clock? We have tried repeatedly upon the clock which stands upon the landing of the kitchen stairs. We find wheels and axles, levers, screws, pulleys, &c., but neither of us know what to call the *pendulum*. Is it a *mechanical* power? and, if so, why have you not included it in your classification?

F. The pendulum is not called a mechanical power, because it does not confer any mechanical advantage. It serves as a *regulator* of motions by means of the force of gravity, but itself requires a distinct power, called "a maintaining power," to keep it from subsiding into rest.

The maintaining power is a weight or a spring. The former in descending, or the latter in uncoiling, communicates motion to a train of wheels, the last of which, called the scape-wheel, is notched in a peculiar way, and is caught by a tooth or hook at every beat of the pendulum. The weight would run rapidly down but for this contrivance; as it is, tooth by tooth is allowed to escape at each beat of the pendulum; and so, while the latter regulates the motion, it is prevented subsiding to rest, by the slight impulse it gets from each tooth. When, instead of a step by step motion, a continuous movement is required, a *conical pendulum* is used; so called from its motion describing a cone. It is suspended over the clock movement by a universal joint; and touches a horizontal arm of the clock with a vertical wire, extending from the bob downwards. Its motion resembles that of the balls or governor of a steam-engine, such as you see in many grocers' shops, and which I will some day describe to you. The Astronomer Royal uses such a pendulum to give uniform motion to a metal drum, which will carry the means for recording the passage of stars in front of the transit telescope, and for other astronomical purposes.

C. I perceive that the *length* of the pendulum has something to do with the time of its vibration; for the pendulum of the chamber clock, which stands upon the drawing-room mantelpiece, is much shorter than that of the kitchen clock; and I observe that it performs its vibrations in much less time. Are the laws of the pendulum simple enough for my sister and me to comprehend them?

F. With your usual attention, my dear children, I doubt not that you will find the laws of pendulums quite within your comprehension. The most important are these: — 1. The times of vibration of the same pendulum in very small arcs are all equal. 2. The velocity of the bob in the lowest point will be as the length of the chord of the arc, which it describes in its descent. 3. The times of vibrations of different pendulums, in similar arcs, are proportional to the square roots of their respective lengths. 4. Hence the lengths of pendulums are as the squares of the times of vibration. 5. In the latitude of London, a simple pendulum, that is, a fine thread with a small ball at its end, will vibrate once in a second in a small arc, if its length be 39 inches and a fifth. There are many other curious properties, but perhaps these will be sufficient for your present purpose.

E. More, I fear, than I shall remember just yet; but, with dear Charles's kind assistance, I hope I shall surmount all dif-

ficulties in due time. Let me try; and let Charles set me right, if you please, papa.

A pendulum which vibrates seconds is $39\frac{1}{5}$ inches in length, and the lengths are as the square roots of the times: therefore, the length of a half-second pendulum is ——. Now I cannot succeed. I must refer to you, Charles, for I suspect it requires a knowledge of fractions.

C. It does, Emma. The square of $\frac{1}{2}$ is $\frac{1}{4}$; that is, the square of 2 in the denominator is 4 in the denominator. Do you understand that?

E. Yes, Charles.

C. Well, then: a fourth of $39\frac{1}{5}$ is 9 inches and $\frac{4}{5}$, which is the length of a half-second pendulum—am I right, papa?

F. Perfectly. Upon the same principles you can, I suppose, tell the length of a pendulum to vibrate in quarters of a second.

C. Yes; it is only to take the quarter of the last number, or the 16th part of the original length of the second's pendulum; thus we obtain 2 inches and $\frac{9}{20}$ for the length of the quarter-second pendulum.

E. I now see why the pendulum of the little chamber clock is shorter than that of the kitchen clock; and I think I can tell the length of a two-second and of a three-second pendulum. Let me try; and do not you interrupt me, Charles, unless I make a mistake. The square of 2 is 4, so that the two-second pendulum is four times the length of the second pendulum; and for the same reason, because the square of 3 is 9, the three-second pendulum is 9 times the length of that which vibrates once in a second; and so on for other numbers. I think we may now quit this subject; what say you, Charles?

C. I should like first to ask papa for some information respecting the great pendulum experiment, that was exhibited in the theatre of the Polytechnic Institution. I saw a great ball vibrating from the ceiling over a round table, on which were some heaps of sand; but I was too late to hear the description.

F. M. Foucault, a Frenchman, had demonstrated in 1851 a property in the pendulum that had barely been noticed before, and had not at all been studied. He showed that a free pendulum changes apparently its plane of vibration, and that really it continues to vibrate in the same plane.

E. What do you mean by a *free* pendulum, and by plane of vibration?

F. A heavy ball suspended to a long wire is free to move backwards and forwards, or to the right and left, or in any other direction. And the direction in which it moves is the plane of vibration. For instance, if such a pendulum were suspended

over the nave of our church, and were set in vibration in a direct line from the organ to the chancel, viz. east and west, it would in a very few minutes show a marked alteration in its direction. When near the chancel, the ball would be seen to have got more towards the south aisle, and when at the other end of the vibration, or near the organ, it would be found nearer to the north aisle. In fact, if a line were extended under the ball to mark its direction, and were altered as the direction alters, it would be found to move in the direction of the sun, viz. from east to west.

C. Can we try this ourselves from the roof of the barn?

F. Certainly: and instead of starting the ball with your hand, hang it in a loop of thin packthread to one side of the barn; and when it is perfectly at rest, burn the packthread, and so liberate the ball. You will very soon see a change in the direction. It will change to the extent of about 12° or the 30th part of a circle in an hour. The heaps of sand were touched in order, at the Polytechnic Institution, in proportion as the plane of vibration varied from the direction originally imparted to it. In accurate experiments, extreme care is required that the suspension be perfect and regular.

E. You said, that the plane of vibration *apparently* changes: why, it really changes, if I understand you correctly.

F. It is the church or barn, with which you are comparing it, that changes. The pendulum continues in its original direction; and as the earth moves on from west to east, the path of the pendulum is left behind, and *seems* to move with the sun from east to west. If the ball were large enough to contain you within it, and you were to peep through holes in its equator, you would literally and truly *see the earth move.* The hourly arcs of deviation have been found, in Paris, 11° 30′; Bristol, 11° 42′; Dublin, 12°; York, 13°.

C. But the earth revolves in 24 hours, and the circumference being 360°, gives 15° per hour, which does not agree with any one of the experiments.

F. I am afraid I cannot enable you quite to understand the combined motions that occur in our latitudes, to produce this anomalous result. We are obliged to hang the pendulum to something, and this something is carried onward with the earth, which gives a kind of backward twist to the plane of vibration, and complicates the result. But, suppose the experiment to be made at the very pole of the earth, and the wire to be hung to the centre of a dome exactly over the pole. The earth would rotate round this centre; and therefore the point of suspension would not move. The consequence would be that the plane

would progress exactly 15° per hour; and if the pendulum could keep long enough in motion, it would keep pace with the sun, and complete an entire circuit in 24 hours.

E. Then it appears that the direction in space originally given to the pendulum is retained throughout; and that its direction, in reference to the earth and things on the earth, is only relative; and that its rate of variation depends upon the amount of motion imparted to the point of suspension by the rotation of the earth.

F. I am glad to see that you have gathered the leading facts of this remarkable phenomenon.

M. Foucault has just described a new instrument which he terms a *Gyroscope;* and by which he has discovered some new features in bodies having free liberty to move in all directions. Conceive a hoop suspended from the ceiling by a thread; within this a smaller hoop, balanced horizontally, and very free to move; within this a solid metal ring, also freely balanced, and with its axis at right angles to that of this smaller hoop. When rapid rotation is communicated to the metal ring, the whole apparatus, which before was sensitive to a breath of air, takes a determinate steadiness in space, with remarkable energy; and its axis *follows exactly the movement of celestial space.* He has mounted a telescope on this axis; and by looking through it at terrestrial objects, he actually *sees the earth move.*

By allowing this ring liberty to move only in certain given directions, he has arrived at the following remarkable conclusions: —

"Every body turning round an axis, free to direct itself without moving out of the horizontal plane, furnishes a new sign of the rotation of the earth; for this rotation developes a directive force, which *draws the axis of the body towards the meridian,* and induces this body *to turn in the same direction as the globe.*

"So that, without the assistance of any astronomical observation, the rotation of a body on the surface of the earth enables us *to point out the plane of the meridian.*

"And, every body, turning round an axis that is free to direct itself without moving out of the meridian, enjoys the property of adjusting itself *parallel to the axis of the world,* and so as to *turn in the same direction as the earth.*"

ASTRONOMY.

CONVERSATION I.

OF THE FIXED STARS.

Tutor — Charles — James.

Charles. How brilliant the stars are this evening!

James. They are; and the longer I keep my eyes fixed upwards, the more stars there seem: how is it possible to number these stars? and yet I have heard that they are numbered, and even arranged in catalogues according to their apparent magnitude. Pray, sir, explain to us how this is done.

Tutor. This I will do, with pleasure, on some future day; but at present I must tell you, that in viewing the heavens with the naked eye, we are very much deceived in the number of stars, that are visible. It is generally admitted, and on good authority too, that there are never more than one thousand stars visible to the naked eye at any one time.

J. What! can I see no more than a thousand stars if I look all round the heavens? I should suppose there were millions.

T. This number is certainly the limit; and that which leads you to conjecture that the number is so much larger is an optical deception.

J. Are we frequently liable to be deceived by our senses?

T. We are, if we depend on them *singly;* but where we have an opportunity of calling in the experience of one sense to the aid of another, we are seldom subject to this inconvenience.

C. Do you not know, that if you place a small marble in the palm of the left hand, and then cross the second finger of the right hand over the first; and in that position, with your eyes shut, move the marble with those two parts of the two fingers at once, which are not accustomed to come into contact with any object at the same time, that the one marble will appear to the touch as two? In this instance, without the assistance of our eyes, we should be deceived by the sense of feeling.

T. This is to the point, and shows that the judgment, formed by means of a single sense, is not always to be depended upon.

C. I should indeed have thought with my brother that there

were more than a thousand, had you not asserted the contrary; and I am anxious to know how it happens that I am so deceived.

T. You are not so much deceived as you are hasty; look at any small portion of the heavens, and count the stars in it; then make a rude guess at the number of such portions there are in the whole, and a simple multiplication will show you that the number is not nearly so large as you imagine.

C. But I find it difficult to count; the stars dazzle me.

T. Yes; and this helps to deceive you at first; for the rays from each star get confused as they enter your eye, and you are apt to think that you see many more than there really are.

C. I should like to see this illustrated.

T. Bring me your multiplying glass; look through it at the candle: how many do you see? or rather, how many candles should you suppose there were, did you not know that there was but one on the table?

J. A great many; and a pretty sight it is.

C. Let me see; yes, there are, — but I can easily count them; there are sixteen.

T. There will be just as many images of the candle, as there are surfaces on your glass; had there been 60, or 600, then the single candle would have given you the idea of 60 or 600. What think you now about the stars?

J. I can no longer doubt but that a thousand real luminaries may have the power of exciting in my mind the idea of millions; but by looking carefully I get rid of this false idea.

T. I will mention another experiment for the next clear star-light night. Get a long narrow tube, the longer and narrower the better; examine through it any one of the largest fixed stars, which are called stars of the *first* magnitude, and you will find that, though the tube takes in as much sky as would contain many such stars, yet that the single one at which you are looking is scarcely visible, by the few rays which come *directly* from it: this is proof that the brilliancy of the heavens is much more owing to *reflected* and *refracted* light, than to the direct rays flowing from the stars. I will explain these terms when we talk upon Optics.

CONVERSATION II.

Of the Fixed Stars.

C. Another beautiful evening! shall we take the advantage which it offers of going on with our astronomical lectures?

T. I have no objection, for we do not always enjoy such opportunities as this.

J. I wish very much to know how to distinguish the stars, and to be able to call them by their proper names.

T. This you may very soon learn; a few evenings well improved will enable you to distinguish all the stars of the first magnitude which are visible, and all the relative positions of the different constellations.

J. What are constellations, sir?

T. The ancients, that they might the better distinguish and describe the stars, divided them into constellations, that is, systems of stars, each system consisting of such stars as were near to each other; they gave them the names of such men or things as they fancied the space which they occupied in the heavens represented.

C. Is it then perfectly arbitrary, that one collection is called the *Great Bear*, another *the Dragon*, a third *Hercules*, and so on?

T. It is; and though there have been additions to the number of stars in each constellation, and various new constellations invented by modern astronomers, yet the original division of the stars into these collections was one of those few arbitrary inventions which have descended without alteration, otherwise than by addition, from the days of Ptolemy down to the present time. Do you know how to find the four cardinal points, as they are usually called, the North, South, West, and East.

J. O yes; I know that if I look at the sun at twelve o'clock at noon, I am looking to the south; my back is toward the north; the west is on my right hand, and the east is on my left.

T. But you must learn to find these points without the assistance of the sun, if you wish to be a young astronomer.

C. I have often heard of the *North-pole star*; that will perhaps answer the purpose of the sun when he has left us.

T. You are right: do you see those seven stars which are in the constellation of the *Great Bear*? — some people have supposed their position will aptly represent *a plough*; others say that they are more like a *waggon and horses*, — the four stars representing the body of the waggon, and the other three the horses, and hence they are called by some the plough, and by others they are called Charles's wain or waggon. There is a drawing of it; *a b d g* represent the four stars, and *e z* B the other three, fig. 1.

C. What is the star P?

T. That represents the polar star, to which you just now alluded; and you observe, that if a line were drawn through the stars *b* and *a*, and produced far enough, it would nearly touch it.

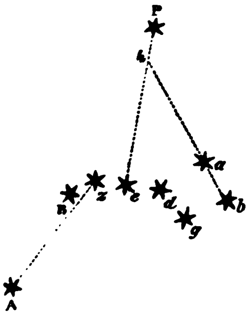


Fig. 1.

J. Let me look at the heavens for it by this guide. There it is, I suppose; it shines with a steady and rather a dead kind of light, and it appears to me that it would be a little to the right of the line, passing through the stars *b* and *a*.

T. It would: now these stars are generally known by the name of the *pointers*, because they point to the north pole, which is situated a little more than two degrees from the star P.

C. Is that star always in the same part of the heavens?

T. Nearly so; it describes so very small a circle round the pole, that it may be *almost* regarded as fixed; and the rest of the starry vault has an apparent motion round this star.

J. I now understand that if I look to the north, by standing with my face to that star, the south is at my back, on my right hand is the east, and the west on my left.

T. Just so; and we can make use of these stars as a kind of standard, in order to discover the relative positions of others.

C. In what way must we proceed?

T. Conceive a line drawn from the star *z* (fig. 1.), leaving B a little to the left, and it will pass through that very brilliant star A near the horizon towards the west.

J. I see the star, but how am I to know its name?

T. Look on the celestial globe for the star *z*, and suppose the line drawn on the globe, as we conceived it done in the heavens, and you will find the star and its name.

C. Here it is;—its name is Arcturus.

T. Take the figure (fig. 1.), and place Arcturus at A, which is its relative position, in respect to the constellation of the Great Bear. Now if you conceive a line drawn through the stars *g* and *b*, and extended a good way to the right, it will pass just above another very brilliant star. Examine the globe as before and find its name.

C. It is *Capella*, the *little goat.*

T. Now whenever you see any of these stars, you will know where to look for the others without hesitation.

J. But do they never move from their places?

T. With respect to us they seem to move together with the whole heavens. But they always remain in the same relative position with respect to each other. Hence they are called

fixed stars, in opposition to the *planets*, which, like our earth, are continually changing their places, both with regard to the fixed stars and to themselves also.

C. I now understand pretty well the method of acquiring a knowledge of the names and places of the stars.

CONVERSATION III.

Of the Fixed Stars, and the Ecliptic.

T. I dare say that you will now have no difficulty in finding the north polar star.

J. No; unless that and the other stars have changed their places.

T. They always keep the same position with respect to each other, though their situation, with regard to the heavens, will be different at different seasons of the year, and in different hours of the night. Let us go into the garden.

C. The stars are all in the same places as we left them last evening. Now, sir, if we conceive a straight line drawn through the two stars in the *Great Bear*, which are marked *d g*, and to extend a good way down, it will pass or nearly pass through a very bright star, though not so bright as *Arcturus* or *Capella;* what is that called?

T. It is a star of the second magnitude; and if you refer to the celestial globe, you will find it is called *Regulus* or *Cor Leonis*, the *Lion's Heart.*

C. But have all the stars names; or how are they specified?

T. If you look on the globe, you will observe that they are distinguished by the different letters of the Greek alphabet; and in those constellations, in which there are stars of different apparent magnitudes, the largest is α alpha, the next in size β beta, the third γ gamma, the fourth δ delta, and so on.

J. Is there any particular reason for this?

T. The adoption of the characters of the Greek alphabet rather than any other was perfectly arbitrary; it is, however, of great importance, that the same characters should be used in general by astronomers of all countries, for by this means the science is in possession of a sort of universal language.

C. Will you explain how this is?

T. Suppose an astronomer in North America, Asia, or any other part of the earth, observe a comet in that part of the heavens where the constellation of the *Great Bear* is situated,

and he wishes to describe it to his friend in Great Britain, in order that he may know whether it was seen by the inhabitants of this island. For this purpose he has only to mention the time when he discovered it; its position, as nearest to some one of the stars, calling it by the Greek letter by which it is designated; and the course which it took from one star towards another. Thus he might say, that on such a time he saw a comet near δ in the *Great Bear*, and that its course was directed from δ to β, or any other, as it happens.

C. Then if his friend here had seen a comet at the same time, he would, by this means, know whether it was the same or a different comet?

T. Certainly; and hence you perceive of what importance it is, that astronomers in different countries should agree to mark the same stars and systems of stars by the same characters. But to return to that star to which you just called my attention, the *Cor Leonis;* it is not only a remarkable star, but its position is also remarkable: it is situated in the *ecliptic.*

J. What is that, sir?

T. The *ecliptic* is an imaginary great circle in the heavens, which the sun *appears* to describe in the course of a year. If you look on the celestial globe, you will see it marked with a *red* line.

J. But the sun seems to have a circular motion in the heavens every day?

T. It does; and this is called its apparent *diurnal*, or daily motion, which is very different from the path it appears to traverse in the course of a year. The diurnal path is manifest to the most careless observer; but the annual path requires some thought to trace it out.

C. And what is the *green* line which crosses it?

T. It is called the *equinoctial.* If you can conceive the plane of the terrestrial equator to be produced to the sphere of the fixed stars, it would mark out this circle in the heavens, which would cut the *ecliptic* in two parts; and one of these would make an angle with the other of about 23½ degrees.

J. Can we trace the circle of the *ecliptic* in the heavens?

T. It may be done with tolerable accuracy by two methods: *First*, by observing several remarkable fixed stars, to which the moon in its course seems to approach; the *second* method is by observing the places of the planets.

C. Is the moon then always in the ecliptic?

T. Not exactly so; but it is always either in the ecliptic, or within five degrees and a third of it on one side or the other. The principal planets also—by which I mean Mercury, Venus,

Mars, Jupiter Saturn, and Herschel—are never more than eight degrees distant from the line of the ecliptic.

J. How can we trace this line, by help of the fixed stars?

T. By comparing the stars in the heavens with their representatives on the artificial globe. I will mention to you the names of those stars, and you may first find them on the globe and then refer to as many of them as are now visible in the heavens. The first is in the *Ram's* horn, *a Arietis*, about ten degrees to the *north* of the ecliptic; the second is the star *Aldebaran* in the *Bull's* eye, six degrees south of the ecliptic.

C. Then if at any time I see these two stars, I know that the ecliptic runs between them, and nearer to Aldebaran than to that in the Ram's horn.

T. Yes: now carry your eye eastward to a distance somewhat greater from Aldebaran than that is east of *a* Arietis, and you will perceive two bright stars at a small distance from one another, called *Castor* and *Pollux;* the lower one, and that which is least brilliant, is Pollux, seven degrees on the north side of the ecliptic. Following the same track, you will come to *Regulus*, or *Cor Leonis*, which, I have already observed, is exactly in the line of the ecliptic. Beyond this, and only two degrees south of that line, you will find the beautiful star in the Virgin's hand, called *Spica Virginis*. You then arrive at *Antares*, or the *Scorpion's Heart*, five degrees on the same side of the ecliptic. Afterwards you will find *a Aquilæ*, which is situate nearly thirty degrees north of the ecliptic; and farther on is the star *Fomalhaut* in the fish's mouth, about as many degrees south of that line. The ninth and last of these stars is *Pegasus*, in the wing of the flying horse, which is north of the ecliptic nearly twenty degrees.

J. Upon what account are these nine stars particularly noticed?

T. They are selected as the most conspicuous stars near the moon's orbit, and are considered as proper stations, from which the moon's distance is calculated for every three hours of time; and hence are constructed those tables in the "Nautical Almanac," by means of which navigators, in their most distant voyages, are enabled to estimate, on the trackless ocean, the particular part of the globe on which they are.

C. What do you mean by the "Nautical Almanac?"

T. It is a kind of National Almanac, intended chiefly for the use of seamen. It was begun in the year 1767, by Dr. Maskelyne, the Astronomer Royal; and is published several years in advance for the convenience of ships going out upon long voyages. This work has been found eminently important in the

course of voyages round the world; and indeed it is so highly useful to all who are engaged in navigation, that mariners always regard it as an indispensable companion, except in mere coasting voyages.

CONVERSATION IV.

Of the Ephemeris.

C. Your second method of tracing the ecliptic was by means of the position of the planets: will you explain that now?

T. I will; and, to render you perfectly qualified for observing the stars, I will explain the use of White's Ephemeris *, a little book which is published annually, and which is a necessary companion to every young astronomer.

J. Must we understand all this to study the stars?

T. You must; or some other book of the same kind †, if you would proceed on a rational plan. Besides, when you know the use of this book, which you will completely with half an hour's attention, you have nothing more to do in order to find the position of the planets at any day of the year, than to turn to that day in the Ephemeris, and you will instantly be directed to those parts of the heavens, or the place in the zodiac, in which the different planets are situated.

J. What do you mean by the Zodiac?

T. It is an imaginary broad circle or belt surrounding the heavens, about sixteen degrees wide; along the middle of which runs the ecliptic. The term Zodiac is derived from a Greek word signifying an animal, because each of the twelve signs formerly represented some animal; that which we now call Libra being by the ancients reckoned a part of Scorpio. As it will be useful for you to have the names of the twelve signs in your memory, as well as the order in which they stand, I will repeat some lines written by Dr. Watts, which will be easily remembered:

"The *Ram*, the *Bull*, the *heavenly Twins*,
And next the *Crab* the *Lion* shines,
The *Virgin* and the *Scales*;
The *Scorpion*, *Archer*, and *Sea-Goat*,
The *Man* that holds the *watering-pot*,
And *Fish* with glittering tails."

* "*White's Cœlestial Atlas, or an improved Ephemeris*, wherein are contained the geocentric places of the Planets, the Eclipses, Occultations, and other Celestial Phenomena of the Year; also, a complete Almanack, containing the Feasts and Fasts of the Church of England, the times of the Lunations, the rising and setting of the Sun and Moon and Planets, &c., adapted to the meridian and latitude of Greenwich," &c. &c., is the title of a shilling book, edited, for 1853, by W. S. B. Woodhouse, F.R.A.S., that has been published for one hundred and thirty-three years, by the Company of Stationers.

† The "Illustrated London Almanack," of which the astronomical part is edited by J. Glaisher, Esq., F.R.S., is a very useful and instructive book of reference.

These signs are generally expressed by their Latin names; and, for convenience of reference, each sign has a symbolic representation. The following are the symbols, with the respective Latin names attached, and which are given in p. 46. of the Ephemeris:

♈ Aries.	♌ Leo.	♐ Sagittarius.
♉ Taurus.	♍ Virgo.	♑ Capricornus.
♊ Gemini.	♎ Libra.	♒ Aquarius.
♋ Cancer.	♏ Scorpio.	♓ Pisces.

In astronomy, every circle is divided into 360 degrees, consequently each of the twelve signs contains 30 degrees; every degree is divided into 60 minutes, and each minute is subdivided into 60 seconds. The symbols for these terms are—degrees (°), minutes (′), seconds (″). Hence ♎ 25° 11′ 45″, means 25 degrees, 11 minutes, 45 seconds in Libra.

C. Are there not also many other symbolic signs?

T. There are signs for the sun, moon, and planets; and also for their relative positions, &c. They are all given in the same page, and are as follows:

☉ The Sun.	♂ Mars.
	♃ Jupiter.
○ Full Moon.	♄ Saturn.
● New Moon.	♅ Uranus.
☽ First Quarter.	♆ Neptune.
☾ Last Quarter.	
	⚶ Vesta.
☿ Mercury.	⚵ Juno.
♀ Venus.	⚳ Ceres.
⊕ Earth.	⚴ Pallas.

The symbols for the new asteroids will be given hereafter.

C. What is the meaning of the word Ephemeris?

T. It is derived from two Greek words, signifying "upon days;" and is a kind of diary or journal of the position and relations of the heavenly bodies. You will find that the double page contains no less than twenty-one columns. We will take a hasty glance at these; and you will thus become acquainted with many astronomical terms, and will see the large amount of information that is necessarily collected together for the guidance of those who use the Ephemeris.

Col. I. gives the day of the month. We select Jan. 2d for illustration.

Col. II. gives the day of the week, and, if Sunday, the Sunday letter for 1853, B.

Col. III. gives the festival, or 2d Sunday after Christmas.

Col. IV. the time the sun rises, 8h. 9m., or 9 minutes past 8.

Col. V. the time of sunset, 3h. 59m., or 1 minute to 4.

Col. VI. the difference between *mean time* and *apparent* time, on this day 4m. 27s. The clock, which represents mean time, indicates noon 4 minutes and 27 seconds before the sun, representing apparent time, reaches the meridian, or becomes due south. When speaking of the *Equation of Time*, I shall be able to give you some more information upon this point.

Col. VII. gives the sun's right ascension, which is its distance at noon from a meridian passing through the commencement of the ecliptic, or the first point of the constellation Aries. It is expressed in time, 18h. 52m. 35s. As the earth, which is in circumference a circle of 360°, revolves in 24 hours, an hour represents 15°; so that time and degrees are mutually convertible. On March 21st at noon the sun is only 2m. 58s. from the meridian; so that a little before noon on that day it is on the meridian.

Col. VIII. shows the declination of the sun at noon, or its distance north or south from the equator; it is now 22° 54′ south. Its greatest distance south is on December 21st, when it is 23° 28′.

Col. IX. is the sun's *longitude*, or place in the ecliptic expressed by the sign, in degrees and minutes, &c. At noon, on January 2d, it is at 11° 4′ 21″ of Capricornus.

The sun's *latitude*, or distance N. or S. from the ecliptic, is extremely small, and varies but little, and that slowly. It is given each sixth day in a small column at the top of the right-hand page: it is on January 1st six-tenths of a second north of the ecliptic.

Col. X. contains a guide to the relatvie distance between the centre of the earth and the centre of the sun. As it is expressed in logarithms, which you have not yet studied, I will not attempt to explain.

Col. XI. shows the distance in time of the first point of Aries from the meridian, at noon, by a clock keeping mean time. It is called siderial time, and refers to the time between the departure of a meridian of the earth from a star till its next return to it.

Cols. XII. to XIX. give particulars respecting the moon; its time of *rising*; and its reaching the *south*, 32 minutes past 5 in the morning; its *right ascension* or distance from the first point of Aries, expressed in time, 12 hours 33 minutes; its *declination*, or distance north or south of the equator, 2° 7′ north; its longitude, or place in the ecliptic, 6° 44′ of Libra; its latitude,

5° 13′ north of the ecliptic; its *semi-diameter*, or the angle 16′ 2″, it would subtend or produce if seen from the centre of the earth; and, finally, its *horizontal parallax*, 58′ 44″, or the greatest angle under which the earth's semi-diameter at the equator would be seen if viewed from the centre of the moon.

Col. XX. gives the time of high water at London Bridge in the morning as 24 minutes past 6; and Col. XXI., the time in the afternoon, viz. 48 minutes past 6.

In addition to this, the top of the left-hand page shows the lunations or times when the moon enters her respective quarters.

C. There are no less than ten more little columns on the top of the right-hand page, some of which explain themselves, — as the *length of the day*, which I have no doubt is the time from sunrise to sunset; — *day increased*, which I see, for January 1st, is six minutes since the shortest day, and goes on increasing day by day. *Daylight begins*, — what is that?

T. It is the time when twilight commences, or the sun is 18° below the horizon. The *sun's hourly motion* is the rate of its change of longitude; its *semi-diameter*, as seen from the centre of the earth; the time of its semi-diameter passing the meridian; and, finally, the time at which it is due east. To these are added the place of the moon's ascending node, of which more hereafter.

C. Are the clock and the sun always different in time?

T. Not always, but very nearly so. If you are in possession of a very accurate and well-regulated clock, and also of an excellent sun-dial, they will be together only four days in a year; now this column in the Ephemeris points out how much the clock is before the sun, or the sun before the clock, for every day in the year.

J. What are the four days in the year when the clock and dial are together?

T. About the 15th of April, the 15th of June, the 1st of September, and Christmas-day.

C. By this table then we may regulate our clocks and watches.

J. In what manner?

C. Examine the time by a good clock or watch, and on a good sun-dial, and observe whether the difference between them answer to the difference set down in the table, opposite to the day of observation.

CONVERSATION V.

Of the Solar System.

T. We will now proceed to the description of the *Solar System*, consisting of the sun and planets, with their satellites or moons; so called from *Sol*, the sun, because the sun is supposed to be fixed in the centre, while the planets, and our earth among them, revolve round him at different distances.

C. But are there not some people who believe that the sun goes round the earth?

T. Yes. It was adopted by Ptolemy, a celebrated astronomer of antiquity, who supposed the earth perfectly at rest, and the sun, planets, and fixed stars to revolve about it every twenty-four hours.

J. And is not that the most natural supposition?

T. If the sun and stars were small bodies in comparison of the earth, and were situated at no very great distance, then the system maintained by Ptolemy and his followers might appear the most probable.

J. Are the sun and stars very large bodies then?

T. The sun is more than a million of times larger than the earth which we inhabit, and many of the fixed stars are probably much larger than he is.

C. What is the reason, then, that they appear so small?

T. This appearance is caused by the immense distance there is between us and these bodies. It is known with certainty that the sun is more than 95 millions of miles distant from the earth, and the nearest fixed star is not less than two hundred thousand times farther from us than even the sun himself.

C. How can any one know this? they must guess.

T. No, it is no guessing; it is a certainty: I will try to show you how it is known. Draw a large circle on the lawn; place your cap on one edge of the circle, and stand yourself on the other side of the circle exactly opposite to your cap; now look carefully at those two fir trees on the hill at a distance.

C. I see them: there is just enough space between them to permit of my seeing the flag-staff on the other side of the hill.

T. Good: now come over to your cap, and look again at the trees, and tell me what you observe.

C. They now appear so close together that the flag-staff is hidden.

T. Exactly so; and if I were to measure the diameter of the circle, and then notice the angle under which you had seen the

trees, a short calculation would enable me to tell you their exact distance.

C. What, without measuring it?

T. Yes. But I see you are going to ask me what this has to do with the stars. I will tell you. Fancy the flag-staff a star, and your two places of observation the situation of the earth at opposite times of the year. A certain star has been examined from two such positions, and it has not changed its place in respect to other stars, as your flag-staff did in respect to the trees. But a short calculation tells us that it *would have changed its place* had it been nearer than I mentioned.

C. But we can form no conception of such distances.

T. No; but several methods have been adopted to assist the mind in comprehending the vastness of these distances. You have some idea of the swiftness with which a cannon-ball proceeds from the mouth of the gun?

J. I have heard at the rate of eight miles in a minute.

T. And you know how many minutes there are in a year.

J. I can easily find out that by multiplying 365 days by 24 for the number of hours, and that product by 60, and I shall have the number of minutes in a year, which number is 525,600.

T. Now if you divide the distance of the sun from the earth by the number of minutes in a year, multiplied by 8, because the cannon-ball travels at the rate of 8 miles in one minute, you will know how long any body issuing from the sun, with the velocity of a cannon-ball, would employ in reaching the earth.

C. If I divide 95,000,000 by 525,600 multiplied by 8, or 4,204,800, the answer will be more than 22, the number of years taken for the journey.

T. Is it then probable that bodies so large, and at such distances from the earth, should revolve round it every day?

C. I do not think it is. We might as reasonably expect the fire to revolve round the meat, instead of the joint rotating in front of the fire.—Will you, sir, go on with the description of the *Solar System*.

T. According to this system, the sun is in the centre, about which the planets revolve from *west* to *east*; that is, if a planet is seen in Aries, it advances to Taurus, then to Gemini, and so on.

J. How many planets are there belonging to the sun?

T. There are eight larger planets, some of which have moons; and no less than twenty-three smaller planets. In fig. 2., c represents the *Sun*, nearest to which revolves *Mercury*, in the orbit marked *a*; then comes *Venus*, in the orbit *b*; next in order,

the *Earth*, *t*, with its moon; then *Mars*, in *e*; then *Jupiter*, in *f*, with its four moons or satellites; afterwards *Saturn*, in *g*,

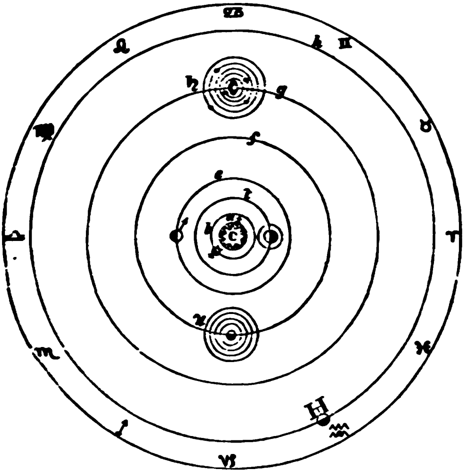


Fig. 2.

with his *eight* moons — the eighth discovered in 1848; then Herschel, with his six moons, in the orbit *h*; and, lastly, *Neptune*, discovered in 1846, who has one moon, and probably more, whose orbit, exterior to Herschel's, is not shown here.

J. For what are the smaller circles, which are attached to several of the larger ones, intended?

T. They are intended to represent the *orbits* of the several satellites or moons belonging to some of the planets.

J. What do you mean by the word orbit?

T. The path described by a planet in its course round the sun, or by a moon round its primary planet, is called its *orbit*. Look to the orbit of the earth in *t*, and you will see a little circle, which represents the orbit in which our moon performs its monthly journey.

C. What are the twenty-three smaller planets, which you have not yet named?

T. The names of the four, which have been known for half a century, and the particulars connected with their discovery, are:

Ceres, discovered by Piazzi, Jan. 1. 1801.
Pallas, „ „ Olbers, March 28. 1802.
Juno, „ „ Harding, Sept. 1. 1804.
Vesta „ „ Olbers, March 19. 1807.

Their orbits are between those of Mars and Jupiter, and the order of their distances from the sun is Vesta, Juno, Ceres, Pallas. The other nineteen, which are very recent discoveries, will be described with Neptune in another conversation. Comets also are included in the solar system.

CONVERSATION VI.

Of the Figure of the Earth.

T. We will now consider each part of the solar system separately: and since we are most of all concerned with the *earth*, we will begin with that body.

J. You promised to give us some reason why this earth must be in the form of a globe, and not a mere extended plane, as it appears to common observation.

T. Suppose you were standing by the sea-shore, on a level with the water, and at a very considerable distance, as far as the eye can reach, you observe a ship approaching; what ought to be the appearance, supposing the surface of the sea to be a flat plane?

C. We should, I think, see the whole ship at once, that is, the hull would be visible as soon as the top-mast.

T. It certainly must, or indeed rather sooner, because the body of the vessel being so much larger than a slender mast, it must necessarily be visible at a greater distance.

J. Yes; I can see the steeple of a church at a much greater distance than I can discern the lightning conductor which is upon it.

T. Well, but the top-mast of a vessel at sea is always in view some little time before the hull of the vessel can be discerned. Now, if the surface of the sea be globular, this ought to be the appearance, because the protuberance or swelling of the water between the vessel and the eye of the spectator, will hide the body of the ship some time after the pennant is seen above.

C. In the same way as if a high building, a church for instance, were situated on one side of a hill, and I was walking up the opposite side, the steeple would come first in sight; and,

as I advanced towards the summit, the other parts would come successively in view.

T. Your illustration is quite to the purpose. In the same way two persons, walking up a hill on the opposite sides, will perceive each other's heads first; and as they advance to the top, the other parts of their bodies will become visible. With respect to the ship, the following figure will convey the idea

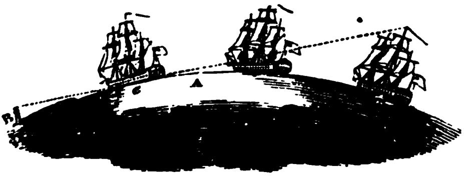


Fig. 3.

very accurately. Suppose B A C represent a small part of the curved surface of the sea; if a spectator stand at B, while a ship is at C, only a small part of the mast is visible to him; but, as it advances, more of the ship is seen, till it arrive at *e*, when the whole will be in sight.

C. When I stood by the sea-side, the water did *not* appear to me to be curved.

T. Perhaps not; but its convexity may be discovered upon any still water: as upon a river, which is extended a mile or two in length; for you might see a very small boat at that distance while standing upright. If, then, you stoop down so as to bring your eye near the water, you will find the surface of it rising in such a manner as to cover the boat, and intercept its view completely. Another proof of the globular figure of the earth is, that it is necessary for those who are employed in cutting canals, to make a certain allowance for the convexity; since the true level is not a straight line, but a curve which falls below it eight inches in the first mile.

C. I have heard of people sailing round the world, which is another proof, I imagine, of the globular figure of the earth.

T. It is a well-known fact that navigators have set out from a particular port, and, by steering their course continually westward, have at length arrived at the same place from whence they first departed. Now had the earth been an extended plane, the longer they had travelled, the farther must they have been from home.

C. How is it known that they continued the same course?

T. By means of the mariner's compass, which I will explain

on a future opportunity; the method of sailing on the ocean by one certain track, is nearly as sure as travelling on the high road. By this method, Ferdinand Magellan sailed, in the year 1519, from the western coast of Spain, and continued his voyage in a western course. He was killed in the Philippine islands; but his ship arrived after 1124 days in the same port from which it had sailed. The same was done by Sir Francis Drake, Lord Anson, Captain Cook, and many others.

C. Is then the common terrestrial globe a just representation of the earth?

T. It is, with this small difference, that the artificial globe is a perfect sphere, whereas the earth is a spheroid, the diameter from *pole* to *pole* being about 37 miles shorter than that at the *equator*.

C. What is a *spheroid?*

T. An egg is an *oblong* spheroid: an orange is an *oblate* spheroid. The earth is an *oblate* spheroid; but it is not nearly so flat in proportion at the poles as the orange is.

J. What are the poles, sir?

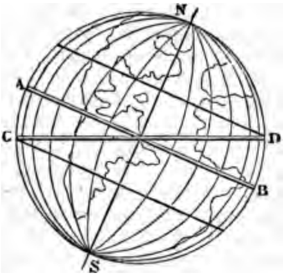


Fig. 4.

T. In the artificial globes there is an axis N S about which it turns; now the two extremities or ends of this axis N and S are called the poles.

C. Is there any axis belonging to the earth?

T. No; but as we shall to-morrow show, the earth turns round once in every twenty-four hours, so astronomers imagine an axis upon which it revolves as upon a centre, the extremities of which imaginary axis are the poles of the earth; of these, N, the north pole, points at all times exactly to the north pole of the heavens, which we have already described, and which is, as you recollect, within two degrees of the polar star in the diagram, *fig.* 1.

J. And how do you define the *equator?*

T. The *equator* A B (in *fig.* 4.) is the circumference of an imaginary circle passing through the centre of the earth, perpendicular to the axis, N S, and at equal distances from the poles.

C. And I think you told us, that, if we conceived this circle extended every way to the fixed stars, it would form the *celestial equator.*

T. I did; it is also called the *equinoctial*, and you must not

forget, that, in this case, it would cut the circle of the ecliptic C D in two points.

J. Why is the *ecliptic* marked on the terrestrial globe, since it is a circle peculiar to the heavens?

T. Though the *ecliptic* be peculiar to the heavens and the *equator* to the earth, yet they are both drawn on terrestrial and celestial globes, in order, among other things, to show the position which these imaginary circles have in relation one to another.

CONVERSATION VII.

Of the Diurnal Motion of the Earth.

T. Having seen that the earth is a globe, I will show you that this globe turns on an imaginary axis every twenty-four hours; and thereby causes the succession of day and night.

C. I shall be glad to hear how this can be proved; for if, in the morning, I look at the sun when rising, it appears in the east, at noon it has travelled to the south, and in the evening I see it in the western part of the heavens.

J. Yes, and we observed the same last night (March the 1st) with respect to *Arcturus*, for about eight o'clock it had just risen in the north-east part of the horizon, and when we went to bed two hours after, it had ascended a good height in the heavens, evidently travelling towards the west.

T. It cannot be denied that the heavenly bodies appear to rise in the east and set in the west; but the *appearance* will be the *same* to us, whether those bodies revolve about the earth while that stands still, or they stand still while the earth turns on its axis the contrary way.

C. Will you explain this, sir?

T. Suppose G R C B to represent the earth, T the centre on which it turns from west to east, according to the order of the letters G R C B. If a spectator on the surface of the earth at R see a star at H, it will appear to him to have just risen; if now the earth be supposed to turn on its axis a fourth of a revolution, the spectator will be carried from R to C, and the star will be just over his head; when another fourth part of the revolution is completed, the spectator will be at B, and to him

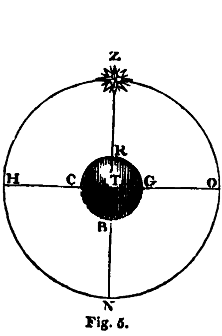


Fig. 5.

the star at H will be setting, and will not be visible again till he arrive by the rotation of the earth, at the station E.

C. To the spectator, then, at E, the appearance would be the same whether he turned with the earth into the situation B, or the star at H had described, in a contrary direction, the space H Z O in the same time.

T. It certainly would.

J. But if the earth really turned on its axis, should we no perceive its motion?

T. The motion of the earth, in its diurnal rotation, being subject to no impediments by resisting obstacles, cannot affect the senses. In the same way ships on a smooth sea are frequently turned entirely round by the tide, without the knowledge of those persons who happen to be busy in the cabin, or between the decks.

C. That is, because they pay no attention to any other object but the vessel in which they are. Every part of the ship moves with themselves.

J. But if, while the ship is turning, without their knowledge, they happen to be looking at fixed distant objects, what will be the appearance?

T. To them, the objects which are at rest will appear to be turning round the contrary way. In the same manner we are deceived in the motion of the earth round its axis; for, if we attend to nothing but what is connected with the earth, we cannot perceive a motion of which we partake ourselves, and if we fix our eyes on the heavenly bodies, the motion of the earth being so easy, they will appear to be turning in a direction contrary to the real motion of the earth.

C. I have sometimes seen a skylark hovering and singing over a particular field for several minutes together; now if the earth is continually in motion while the bird remains in the same part of the air, why do we not see the field, over which he first ascended, pass from under him?

T. Because the atmosphere in which the lark is suspended is connected with the earth, partakes of its motion, and carries the lark along with it; and therefore, independently of the motion given to the bird by the exertion of its wings, it has another in common with the earth, yourself, and all things on it, and being common to us all, we have no methods of ascertaining the fact by means of the senses.

J. Though the motion of a ship cannot be observed, without objects at rest to compare with it, yet I cannot help thinking that, if the earth moved, we should be able to discover it by means of the stars, if they are fixed.

T. Do you not remember once sailing very swiftly on the river, when you told me that you thought all the trees, houses, &c., on its banks were in motion?

J. I now recollect it well; and I had some difficulty in persuading myself that it was not so.

C. This brings to my mind a still stronger deception of this sort: when travelling with great speed on the railway, I suddenly waked from a sleep, and I could scarcely help thinking, for several minutes, but that the trees and hedges were running away from us, and not we from them.

T. I will mention another curious instance of this kind; if you ever happen to travel pretty swiftly in a carriage, by the side of a field ploughed into long narrow ridges, and perpendicular to the road, you will think that all the ridges are turning round in a direction contrary to that of the carriage.

C. You have already given us one other proof of the rotation of the earth on its axis, which although it was not self-evident, — I mean the famous pendulum experiment,—but required no small exercise of reason, yet, when associated with all this other evidence, it cannot but be recognised as a most forcible proof.

T. If the earth (*fig.* 4.) turns on its axis in 24 hours, at what rate will any part of the equator A B move?

C. To determine this we must find the measure of its circumference, and then, dividing this by 24, we shall get the number of miles passed through in an hour.

J. Just so; now call the semi-diameter of the earth 4000 miles, which is rather more than the true measure.

J. Multiplying this by six* will give 24,000 miles for the circumference of the earth at the equator, and this, divided by 24, gives 1000 miles for the space passed through in an hour, by an inhabitant of the equator.

T. You are right. The sun, I have already told you, is 95 millions of miles distant from the earth; tell me, therefore, Charles, at what rate that body must travel to go round the earth in 24 hours.

C. I will; 95 millions multiplied by 6 will give 570 millions of miles for the length of his circuit; this divided by 24 gives nearly 24 millions of miles for the space he must travel in an hour, to go round the earth in a day.

* If the reader would be accurate in his calculations, he must take the mean radius of the earth at 3965 miles, and this, multiplied by 6·28318, will give 24,912 miles for the circumference. Through the remainder of this work, the decimals in multiplication are omitted, in order that the mind may not be burdened with odd numbers. It seemed necessary, however, in this place, to give the true semi-diameter of the earth, and the number (accurate to five places of decimals) by which, if the radius of any circle be multiplied, the circumference is obtained. Mr. Playfair makes the longest semi-diameter of the earth to be 3962½ miles, and the shorter 3949½ miles.

T. Which now is the more probable conclusion, either that the earth should have a diurnal motion on its axis of 1000 miles in an hour, or that the sun, which is a million of times larger than the earth, should travel 24 millions of miles in the same time?

J. It is certainly more rational to conclude that the earth turns on its axis, the effect of which you told us was the alternate succession of day and night.

T. I did; and on this and some other topics we will enlarge to-morrow.

CONVERSATION VIII.

Of Day and Night.

J. You propose now, sir, to apply the rotation of the earth about its axis to the succession of day and night.

T. I do; and for this purpose suppose G R C B (*fig.* 5.) to be the earth, revolving on its axis, according to the order of the letters, that is, from G to R, R to C, &c. If the sun be fixed in the heavens at Z, and a line H O be drawn through the centre of the earth T, it will represent that circle, which, when extended to the heavens, is called the *rational horizon.*

C. In what does this differ from the *sensible horizon?*

T. The *sensible horizon* is that circle in the heavens which bounds the spectator's view, and which is greater or less, according as he stands higher or lower. For example: an eye placed at *five* feet above the surface of the earth or sea sees $2\frac{3}{4}$ miles every way; but if it be at 20 feet high, that is, 4 times the height, it will see $5\frac{1}{2}$ miles, or twice the distance.

C. Then the *sensible* differs from the *rational* horizon in this, that the *former* is seen from the surface of the earth, and the *latter* is supposed to be viewed from its centre.

T. You are right; and the rising and setting of the sun and stars are always referred to the *rational* horizon.

J. Why so? They appear to rise and set as soon as they get above, or sink below, that boundary which separates the visible from the invisible part of the heavens.

T. They do not, however; and the reason is this, that the distance of the sun and fixed stars is so great in comparison of 4000 miles (the difference between the surface and centre of the earth), that it can scarcely be taken into account.

C. But 4000 miles seem to me an immense space.

T. Considered separately, they are so; but when compared with 95 millions of miles, the distance of the sun from the earth, they almost vanish as nothing.

J. But do the rising and setting of the moon, which is at the distance of 240 thousand miles only, respect also the rational horizon?

T. Certainly; for 4000 compared with 240 thousand, bear only the proportion of 1 to 60. Now if two spaces were marked out on the earth in different directions, the one 60 and the other 61 yards, should you at once be able to distinguish the greater from the less?

C. I think not.

T. Just in the same manner does the distance of the centre from the surface of the earth vanish in comparison of its distance from the moon. There is a difference, however, connected with what astronomers called *parallax*; but this is not the time to explain that peculiarity.

J. No; our present business is with the succession of day and night.

T. Well, then; if the sun be supposed at Z, it will illuminate, by its rays, all that part of the earth that is above the horizon H O. To the inhabitants at G, its western boundary, it will appear just rising; to those situated at E, it will be noon; and to those in the eastern part of the horizon, C, it will be setting.

C. I see clearly why it should be noon to those who live at E, because the sun is just over their heads; but it is not so evident why the sun must appear rising and setting to those who are at G and C.

T. You are satisfied that a spectator cannot from any place observe more than a semicircle of the heavens at any one time; now what part of the heavens will the spectator at G observe?

J. He will see the concave hemisphere Z O N.

T. The boundary to his view will be N and Z, will it not?

C. Yes: and consequently the sun, at Z, will to him be just coming into sight.

T. Then, by the rotation of the earth, the spectator at G will in a few hours come to E, when, to him, it will be noon; and those who live at E will have descended to C; now what part of the heavens will they see in this situation?

J. The concave hemisphere N H Z, and Z being the boundary of their view one way, the sun will be to them setting.

T. Just so. After which they will be turned away from the sun, and consequently it will be night to them till they come again to G. Thus, by this simple motion of the earth on its axis, every part of it is by turns enlightened and warmed by the cheering beams of the sun.

C. Does this motion of the earth account also for the apparent motion of the fixed stars?

T. It is owing to the rotation of the earth upon its axis, that we imagine the whole starry firmament revolves about the earth in 24 hours.

J. If the heavens appear to turn on an axis, must there not be two points, namely, the extremities of that imaginary axis, which always keep their position?

T. Yes; we must be understood to except the two celestial poles, which are opposite to the poles of the earth: consequently each fixed star appears to describe a greater or a less circle round these, according as it is more or less remote from those celestial poles.

J. If every part of the heavens be thus adorned, why do we not see the stars in the day, as well as the night?

T. Because, in the daytime the sun's rays are so powerful as to render *those* which come from the fixed stars invisible. But if you ever happen to go down into any very deep mine or coal-pit, where the rays of the sun cannot reach the eye, and it be a clear day, you may, by looking up to the heavens, see the stars at noon as well as in the night.

C. If the earth always revolve on its axis in 24 hours, why does the length of the days and nights differ in different seasons of the year?

T. This depends on other causes connected with the earth's *annual* journey round the sun, upon which we will converse the next time we meet.

CONVERSATION IX.

Of the Annual Motion of the Earth.

T. Besides the *diurnal* motion of the earth, by which the succession of day and night is produced, it has another, called its *annual* motion, which is the journey it performs round the sun in 365 days, 5 hours, 48 minutes, and 49 seconds, and which is the cause of the different lengths of the days and nights, and consequently of the different seasons, viz. *Spring*, *Summer*, *Autumn*, and *Winter*.

J. How is it known that the earth makes this annual journey round the sun?

T. I told you yesterday that, through the shaft of a very deep mine, the stars are visible in the day as well as in the night. They are also visible in the daytime, by means of a telescope properly fitted up for the purpose; by this method, the sun and stars are visible at the same time. Now if the sun be seen in a line with a fixed star to-day at any particular hour, it

will, in a few weeks, by the motion of the earth, be found considerably to the east of him; and if the observations be continued through the year, we shall be able to trace him round the heavens to the same fixed star from which we set out; consequently the sun must have made a journey round the earth in that time, or the earth round him.

C. And the sun being a million of times larger than the earth, you will say that it is more natural, that the smaller body should go round the larger, than the reverse.

T. That is a proper argument; but it may be stated in a much stronger manner. The sun and earth mutually attract one another, and since they are in *equilibrio* by this attraction, you know, their momenta must be equal*, therefore the earth, being the smaller body, makes out by its motion what it wants in the quantity of its matter, and of course it is that which performs the journey.

J. But if you refer to the principle of the lever, to explain the mutual attraction of the sun and earth, it is evident that both bodies must turn round some point as a common centre.

T. They do; and that is the common centre of gravity of the two bodies. Now this point between the earth and sun is within the surface of the latter body.

C. I understand how this is; because the centre of gravity between any two bodies, will be as much nearer to the centre of the larger body than to that of the smaller, as the former contains a greater quantity of matter than the latter.

T. You are right: but you will not conclude that, because the sun is a million of times larger than the earth, therefore it contains a quantity of matter a million of times greater than that contained in the earth.

J. Is it then known that the earth is composed of matter more dense than that which composes the body of the sun?

T. The earth is composed of matter four times denser that that of the sun: and hence the quantity of matter in the sun is between two and three hundred thousand times greater than that which is contained in the earth.

C. Then for the momenta of these two bodies to be equal, the velocity of the earth must be between two and three hundred thousand times greater than that of the sun.

T. Just so: and to effect this, the centre of gravity between the sun and earth will be as much nearer to the centre of the sun than it is to the centre of the earth, as the former body contains a greater quantity of matter than the latter: and hence it

* See Mechanics, Conversation XIV.

is found to be several thousand miles within the surface of the sun.

J. I now clearly perceive, that since one of these bodies revolves about the other in the space of a year, and that they both move round their common centre of gravity, that it must of necessity be the earth which revolves about the sun, and not the sun round the earth.

T. Your inference is just. To suppose that the sun moves round the earth is as absurd as to maintain that a millstone could be made to move round a pebble.*

CONVERSATION X.

Of the Seasons.

T. I will now show you how the different seasons are produced by the annual motion of the earth.

J. Upon what do they depend, sir?

T. The variety of the seasons depends, 1st, upon the length of the days and nights, and, 2dly, upon the position of the earth with respect to the sun.

C. But if the earth turn round its imaginary axis every 24 hours, ought it not to enjoy equal days and nights all the year?

T. This would be the case if the axis of the earth N S were perpendicular to a line C E drawn through the centres of the sun

Fig. 6.

and the earth; for then, as the sun always enlightens one half of the earth by its rays, and as it is day at any given place on the globe, so long as that place continues in the enlightened hemisphere, every part, except the two poles, must, during its rotation on its axis, be one half of its time in the light, and the other half in darkness: or, in other words, the days and nights would be equal to all the inhabitants of the earth, excepting to those, if any, who live at the poles.

J. Why do you except the people at the poles?

T. Because the view of the spectator situated at the poles N and S, must be bounded by the line C E; consequently the sun

to him would never appear to rise or set, but would always be in the horizon.

C. If the earth were thus situated, would the rays of the sun always fall vertically on the same part of it?

T. They would: and that part would be E Q the equator; and, as we shall presently show, the heat excited by the sun being greater or less in proportion as its rays come more or less perpendicularly upon any body, the parts of the earth about the equator would be scorched up, while those beyond 40 or 50 degrees on each side of that line and the poles would be desolated by an unceasing winter.

J. In what manner is this prevented?

T. By the axis of the earth N S being inclined or sloped about 23 degrees and a half out of the perpendicular. In this case

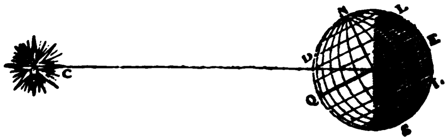


Fig. 7.

you observe, that all the parallel circles, except the equator, are divided into two unequal parts having a greater or less portion of their circumferences in the enlightened than in the dark hemisphere, according to their situation with respect to N the north, or S the south pole.

C. At what season of the year is the earth represented in this figure?

T. At our summer season; for you observe that the parallel circles in the northern hemisphere have their greater parts enlightened, and their smaller parts in the dark. If D L represent that circle of latitude on the globe in which Great Britain is situated, it is evident that about two thirds of it is in the light, and only one third in darkness.

You will remember that *parallels of latitude* are supposed circles on the surface of the earth, and are shown by real circles on its representative, the terrestrial globe, drawn parallel to the equator.

J. Is that the reason why our days towards the middle of June are 16 hours long, and the nights but 8 hours?

T. It is; and if you look to the parallel next beyond that marked D L, you will see a still greater disproportion between the day and night, and the parallel more north than this is entirely in the light.

C. Is it then always day there?

T. To the whole space between that and the pole it is continual day for some time, the duration of which is in proportion to its vicinity to the pole; and at the pole there is a permanent daylight for six months together.

J. And during that time it must, I suppose, be night to the people who live at the south pole?

T. Yes; the figure shows that the south pole is in darkness; and you may observe that, to the inhabitants living in equal parallels of latitude, the one north and the other south, the length of the days to the one will be always equal to the length of the nights to the other.

C. What, then, shall we say to those who live at the equator, and, consequently, who have no latitude?

T. To them the days and nights are *always* equal, and of course twelve hours each in length, and this is also evident from the figure; for in every position of the globe one half of the equator is in the light, and the other half in darkness.

J. If, then, the length of the days is the cause of the different seasons, there can be no variety in this respect to those who live at the equator?

T. You seem to forget that the change in the seasons depends upon the position of the earth with respect to the sun, that is, upon the *perpendicularity* with which the rays of light fall upon any particular part of the earth, as well as upon the length of days.

C. Indeed I did; but does that make any material difference with regard to the heat of the sun?

T. It does; let AB represent a portion of the earth's surface on which the sun's rays fall perpendicularly; let BC represent an equal portion on which they fall obliquely or aslant. It is manifest that BC in the position of the figure, though it be equal to AB, receives but half the light and heat that AB does. Moreover, by the sun's rays coming more perpendicularly, they come with greater force, as well as in greater numbers, on the same place.

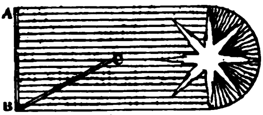


Fig. 8.

CONVERSATION XI.

Of the Seasons.

T. If you now take a view of the earth in its annual course round the sun, considering its axis as inclined 23½ degrees to a

line perpendicular to its orbit, and keeping, through its whole journey, a direction parallel to itself, you will find that, according as the earth is in different parts of its orbit, the rays of the sun are presented perpendicularly to the equator, and to every point of the globe, within 23½ degrees of it both north and south.

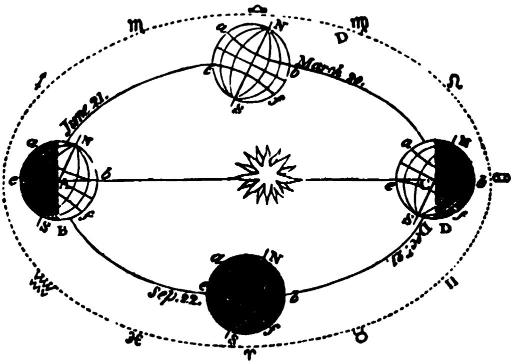


Fig. 9.

The figure represents the earth in four different parts of its orbit, or as it is situated with respect to the sun in the months of March, June, September, and December.

C. The earth's orbit is not made circular in the figure.

T. No; but the orbit itself is nearly circular: we are, however, supposed to view it from the side B D, and therefore, though almost a circle, it appears to be a long ellipse. All circles appear elliptical in an oblique view, as is evident by looking obliquely at the rim of a basin at some distance from you. For the true figure of a circle can only be seen when the eye is directly over its centre. You observe that the sun is not in the centre.

J. I do; and it appears nearer to the earth in winter than in the summer.

T. We are indeed more than three millions of miles nearer to the sun in December than we are in June.

C. Is this possible, when our winter is so much colder than the summer.

T. Notwithstanding this, it is a well-known fact: for it is ascertained that our summer, that is, the time that passes between the vernal and autumnal equinoxes, is nearly eight days longer than our winter, or the time between the autumnal and vernal equinoxes. Consequently the motion of the earth is slower in

the former case than in the latter; and therefore, as we shall see, it must be at a greater distance from the sun. Again, the sun's *apparent* diameter is greater in our winter than in summer; but the apparent diameter of any object increases in proportion as our distance from the object is diminished, and therefore we conclude that we are nearer the sun in winter than in summer. The sun's apparent diameter on January 1st is 32′. 35″; on July 1st, 31′. 30″.

J. But if the earth is farther from the sun in summer than in winter, why are our winters so much colder than our summers?

T. Because first, in the summer, the sun rises to a much greater height above our horizon, and therefore, its rays coming more perpendicularly, a greater number of them, as I showed you yesterday, must fall upon the surface of the earth, and they come also with greater force; which are the principal causes of our great summer's heat. Secondly, in the summer, the days are very long, and the nights short; therefore the earth and air are heated by the sun in the day more than they are cooled in the night. And you must also remember that while it is *summer* with us, it is *winter* elsewhere. So that your objection is not a good one, even if it were sound.

J. But why have we not the greatest heat at the time when the days are longest?

T. The hottest season of the year is certainly a month or two after this, which may be thus accounted for. A body once heated does not become cold again instantaneously, but gradually: now, as long as more heat comes from the sun in the day than is lost in the night, the heat of the earth and air will be daily increasing; and this will evidently be the case for some weeks after the longest day, both on account of the number of rays which fall on a given space, and also from the perpendicular direction of those rays.

J. Will you now explain to us in what manner the seasons are produced?

T. By referring to the last figure, you will observe, that in the month of June, the north pole of the earth inclines towards the sun, and consequently brings all the northern parts of the globe more into light than at any other time in the year.

C. Then to the people in those parts it is summer?

T. It is; but in December, when the earth is in the opposite part of its orbit, the north pole declines from the sun, which occasions the northern places to be more in the dark than in the light; and the reverse at the southern places.

J. Is it then summer to the inhabitants of the southern hemisphere?

T. Yes, it is; and winter to us. In the months of March and September, the axis of the earth does not incline to, nor decline from, the sun, but is perpendicular to a line drawn from its centre. And then the poles are in the boundary of light and darkness, and the sun being directly vertical to, or over the equator, makes equal day and night at all places. Now trace the annual motion of the earth in its orbit for yourself, as it is represented in the figure.

C. I will, sir; about the 20th of March the earth is in Libra, and consequently to its inhabitants the sun will appear in Aries, and be vertical to the equator.

T. Then the equator and all its parallels are equally divided between the light and dark

C. Consequently the days and nights are equal all over the world. As the earth pursues its journey from March to June, its northern hemisphere comes more into light, and on the 21st of that month the sun is vertical to the tropic of Cancer.

T. You then observe, that all the circles parallel to the equator are unequally divided; those in the northern half have their greater portions in the light, and those in the southern half have their larger portions in darkness.

C. Yes; and, of course, it is summer to the inhabitants of the northern hemisphere, and winter to those in the southern.

I now trace it to September, when I find the sun vertical again to the equator, and, of course, the days and nights are again equal. And following the earth in its journey to December, or when it has arrived at Cancer, the sun appears in Capricorn, and is vertical to that part of the earth called the tropic of Capricorn, and now the southern pole is enlightened, and all the circles on that hemisphere have their larger parts in light; and, of course, it is summer to those parts, and winter to us in the northern hemisphere. The 9th column in the Ephemeris, or the Sun's longitude, shows its daily position.

T. Can you, James, now tell me why the days lengthen and shorten from the equator to the polar circles every year?

J. I will try to explain myseli on the subject. Because the sun in March is vertical to the equator, and from that time to the 21st of June it becomes vertical successively to all other parts of the earth between the equator and the tropic of Cancer; and in proportion as it becomes vertical to the more northern parts of the earth, it declines from the southern, and, consequently, to the former the days lengthen, and to the latter they shorten. From June to September, the sun is again vertical successively to all the same parts of the earth, but in a reverse order.

C. Since it is summer to all those parts of the earth where the

sun is vertical, and we find that the sun is vertical twice in the year to the equator, and every part of the globe between the equator and tropics, there must be also two summers in a year to all those places.

T. There are; and in those parts near the equator they have two harvests every year. But let your brother finish his description.

J. From September to December it is successively vertical to all the parts of the earth situated between the equator and the tropic of Capricorn, which is also the cause of the lengthening of the days in the southern hemisphere, and of their becoming shorter in the northern.

T. Can you, Charles, tell me why there is sometimes no day or night for some little time together within the polar circles?

C. The sun always shines upon the earth 90 degrees every way, and when he is vertical to the tropic of Cancer, which is 23½ degrees north of the equator, he must shine the same number of degrees beyond the pole, or to the polar circle; and while he thus shines there can be no night to the people within that polar circle, and, of course, to the inhabitants at the southern polar circle, there can be no day at the same time; for, as the sun's rays reach but 90 degrees every way, they cannot shine far enough to reach them.

T. Tell me, now, why there is but one day and night in the whole year at the poles?

C. For the reason which I have just given, the sun must shine beyond the north pole all the time he is vertical to those parts of the earth situated between the equator and the tropic of Cancer, that is, from March the 21st to September the 20th, during which time there can be no night at the north pole, nor any day at the south pole. The reverse of this may be applied to the southern pole.

J. I understand now, that the lengthening and shortening of the days, and different seasons, are produced by the annual motion of the earth round the sun; the axis of the earth, in all parts of its orbit, being kept parallel to itself.

C. But if the axis of the earth is thus parallel to itself, how can it in all positions point to the pole-star in the heavens?

T. Because the diameter of the earth's orbit A C is as nothing n comparison with the distance of the earth from the fixed stars. Suppose you draw two parallel lines, at the distance of three or four yards from one another, will they not both point to the moon when she is in the horizon?

J. Yes, certainly; for three or four yards cannot be accounted

as anything, in comparison of 240 thousand miles, the distance of the moon from us.

T. Perhaps three yards bear a much greater proportion to 240 thousand miles than 190 millions of miles bear to our distance from the polar star.

CONVERSATION XII.

Of the Equation of Time.

T. You are now, I presume, acquainted with the motions peculiar to this globe, on which we live?

C. Yes: it has first a rotation on its axis from west to east every 24 hours, by which day and night are produced, and also the apparent diurnal motion of the heavens from east to west.

J. The other is its annual revolution in an orbit round the sun, likewise from west to east, at the distance of about 95 millions of miles from the sun.

T. We will now proceed to investigate another curious subject, *viz.* the equation of time, and to explain to you the difference between *equal* or *mean,* and *apparent* time.

C. Will you tell us what you mean by the words *equal* and *apparent,* as applied to time;

T. Equal or *mean* time is measured by a clock, that is supposed to go without any variation, and to measure exactly twenty-four hours from noon to noon; and *apparent* time is measured by the *apparent* motion of the sun in the heavens, or by a good sun-dial.

C. And what do you mean, sir, by the *equation of time?*

T. It is the adjustment of the difference of time, as shown by well-regulated clock and a true sun-dial.

J. Upon what does this difference depend?

T. It depends, *first,* upon the inclination of the earth's axis; and, secondly upon the elliptic form of the earth's orbit; for, as we have already seen, the earth's orbit being an ellipse, its motion is quicker when it is in *perihelion,* or nearest to the sun: and slower when it is in *aphelion,* or farthest from the sun.

C. But I do not yet comprehend what the rotation of the earth has to do with the going of a watch or clock.

T. The rotation of the earth is the most equable and uniform motion in nature, and is completed in 23 hours, 56 minutes, and 4 seconds: this space of time is called a *sidereal* day, because any meridian on the earth will revolve from a fixed star to that star again in this time. But a *solar* or natural day, which our clocks are intended to measure, is the time which

any meridian on the earth will take in revolving from the sun to the sun again, which is about 24 hours, sometimes a little more, but oftener less.

J. What occasions this difference between the solar and sidereal day?

T. The distance of the fixed stars is so great, that the diameter of the earth's orbit, though 190 millions of miles, is, when compared with it, but a point, and therefore any meridian on the earth will revolve from a fixed star to that star again in exactly the same time, as if the earth had only a diurnal motion and remained always in the same part of its orbit. But with respect to the sun, as the earth advances almost a degree eastward in its orbit, in the same time that it turns eastward round its axis, it must make more than a complete rotation before it can come into the same position with the sun that it had the day before. In the same way, as when both the hands of a clock or watch set off together at twelve o'clock, the minute-hand must travel more than a whole circle before it will overtake the hour-hand, that is, before they will be in the same relative position again. Thus the sidereal days are shorter than the solar ones by about four minutes, as is evident from observation.

C. Still I do not understand the reason why the clocks and dials do not agree.

T. A good clock is intended to measure that equable and uniform time which the rotation of the earth on its axis exhibits; whereas the dial measures time by the *apparent* motion of the sun, which, as we have explained, is subject to variation. Or thus: though the earth's motion on its axis be perfectly uniform, and consequently the rotation of the *equator* is likewise equable, yet we measure the length of the natural day by means of the sun, whose *apparent* annual motion is not in the equator, or any of its parallels, but in the ecliptic, which is oblique to it.

J. Do you mean by this, that the equator of the earth, in its annual journey, is not always directed towards the centre of the sun?

T. I do; twice only in the year, a line drawn from the centre of the sun to that of the earth passes through those points where the equator and ecliptic cross one another; at all other times it passes through some other part of that oblique circle, which is represented on the globe by the ecliptic line. Now when it passes through the equator or the tropics, which are circles parallel to the equator, the sun and clocks go together, as far as regards this cause; but at other times they differ, because *equal* portions of the ecliptic pass over the meridian in *unequal* parts of the time, on account of its obliquity.

C. Can you explain this by a figure?

T. It is easily shown by the globe this figure ♈ N ♎ S may represent; ♈ ♎ will be the equator, ♈ ♋ ♎ the northern half of the ecliptic, and ♈ ♑ ♎ the southern half. Make chalk or pencil marks *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, all round the *equator* and *ecliptic*, at equal distances (suppose 20 degrees) from each other, beginning at Aries. Now, by turning the globe on its axis, you will perceive that all the marks in the first quadrant of the *ecliptic*, that is, from Aries to Cancer, come *sooner* to the brazen meridian, than their corresponding marks on the *equator*; those from the beginning of Cancer to Libra come *later*; those from Libra to Capricorn sooner; and those from Capricorn to Aries later.

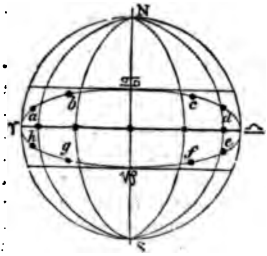


Fig. 10.

Now, time is measured by the sun-dial as represented by the marks on the *ecliptic*; that measured by a good clock, by those on the equator.

C. Then, while the sun is in the first and third quarters, or, what is the same thing, while the earth is travelling through the second and fourth quarters, that is, from Cancer to Libra, and from Capricorn to Aries, the sun is faster than the clocks, and while it is travelling the other two quarters it is slower.

T. Just so: because, while the earth is travelling through the second and fourth quadrants, equal portions of the ecliptic come *sooner* to the meridian than their corresponding parts of the equator: and during its journey through the first and third quadrants, the equal parts of the ecliptic arrive *later* at the meridian than their corresponding parts of the equator.

J. If I understand what you have been saying, the dial and clocks ought to agree at the equinoxes, that is, on the 20th of March and the 23d of September; but if I refer to the Ephemeris, I find that on the former day the clock is almost 8 minutes before the sun; and on the latter day the clock is almost 8 minutes behind the sun.

T. If this difference between time measured by the dial and clock depended only on the inclination of the earth's axis to the plane of its orbit, the clock and dial ought to be together at the equinoxes, and also on the 21st of June and the 21st of December, that is, at the summer and winter solstices; because, on those days the *apparent* revolution of the sun is parallel to

the equator. But I told you there was another cause why this difference subsisted.

C. You did: and that was the elliptic form of the earth's orbit.

T. If the earth's motion in its orbit were uniform, which it would be if the orbit were circular, then the whole difference between *equal* time as shown by the clock, and *apparent* time as shown by the sun, would arise from the inclination of the earth's axis. But this is not the case, for the earth travels when it is nearest the sun, that is, in the winter, more than a degree in 24 hours, and when it is farthest from the sun, that is, in summer, less than a degree in the same time; consequently from this cause the natural day would be of the greatest length when the earth was nearest the sun; for it must continue turning the longest time after an entire rotation, in order to bring the meridian of any place to the sun again: and the shortest day would be when the earth moves the slowest in her orbit. Now these inequalities, combined with those arising from the inclination of the earth's axis, make up that difference which is shown by the equation table, found in the Ephemeris, between good clocks and true sun-dials. There is another cause arising from what astronomers call the *equation of precession in right ascension;* but its effects are very small, and the explication too intricate to be introduced now.

CONVERSATION XIII.

Of Leap-Year, and the Old and New Styles.

J. Before we quit the subject of time, will you give us some account of what is called in our almanacs Leap-year?

T. I will. The length of our year is, as you know, measured by the time which the earth takes in performing her journey round the sun, in the same manner as the length of the day is measured by its rotation on its axis. Now, to compute the exact time taken by the earth in its annual journey, was a work of considerable difficulty. Julius Cæsar was the first person who seems to have attained to any accuracy on this subject.

C. Do you mean the first Roman emperor, who landed also in Britain?

T. I do. He was not less celebrated as a man of science, than he was renowned as a general, being well acquainted with the learning of the Egyptians. He assumed the length of the year to be 365 days and 6 hours, which made it 6 hours longer than the Egyptian year. Now, in order to allow for the odd 6 hours

in each year, he introduced an additional day every fourth year, which accordingly consists of 366 days, and is called *Leap-Year*; while the other three have only 365 days each. From him it was denominated the *Julian* year.

J. It is also called *Bissextile* in the Almanacs; what does that mean?

T. The Romans inserted the intercalary day between the 23d and 24th of February: and because the 23d of February, in their calendar, was called *sexto calendas Martii*, the 6th of the calends of March, the intercalated day was called *bis sexto calendas Martii*, the second sixth of the calends of March, and hence the year of intercalation had the appellation of *Bissextile*. This day was chosen at Rome, on account of the expulsion of Tarquin from the throne, which happened on the 23d of February. We introduce in Leap-Year a new day in the same month, namely, the 29th.

C. Is there any rule for knowing what year is Leap-Year?

T. It is known by dividing the date of the year by 4; if there be no remainder it is Leap-Year; thus 1853 divided by 4, leaves a remainder of 1, showing that it is the first year after Leap-Year.

J. The year, however, does not consist of 365 days and 6 hours, but of 365 days, 5 hours, 48 minutes and 49 seconds.* Will not this occasion some error?

T. It will; and by subtracting the latter number from the former, you will find that the error amounts to 11 minutes and 11 seconds every year, or to a whole day in about 130 years; notwithstanding this, the Julian year continued to be in general use till the year 1582, when Pope Gregory XIII. undertook to rectify the error, which at that time amounted to ten days. He accordingly commanded the ten days between the 4th and 15th of October in that year to be suppressed, so that the 5th day of that month was called the 15th. This alteration took place through the greater part of Europe, and the year was afterwards called the Gregorian year, or *New Style*. In this country, the method of reckoning, according to the New Style, was not admitted into our calendars until the year 1752, when the error amounted to nearly 11 days, which were taken from the month of September, by calling the 3d of that month the 14th.

C. By what means will this accuracy be maintained?

T. The error amounting to one whole day in about 130 years, it is settled by an act of parliament, that the year 1800 and the year 1900, which are, according to the rule just given,

* See Conversation IX.

Leap-Years, shall be computed as common years, having only 365 days in each: and that every *four* hundredth year afterwards shall be a common year also. If this method be adhered to, the present mode of reckoning will not vary a single day from true time, in less than 5000 years.

By the same act of parliament, the legal beginning of the year was changed from the 25th of March to the 1st of January. So that the succeeding months of January, February, and March, up to the 24th day, which would, by the Old Style, have been reckoned part of the year 1752, were accounted as the first three months of the year 1753. Hence we sometimes see such a date as this, Feb. 10. 1774-5, that is, according to the Old Style it was 1774, but according to the New it is 1775, because now the year begins in January instead of March.

The Old Style still prevails in Russia: but in every other part of Europe it is now abolished.

CONVERSATION XIV.

Of the Moon.

T. You are now, gentlemen, acquainted with the reasons for the division of time into days and years.

C. These divisions have their foundation in nature: the *former* depending upon the rotation of the earth on its axis; the *latter* upon its revolution in an elliptic orbit about the sun as a centre of motion.

J. Is there any natural reason for the division of years into weeks, or of days into hours, minutes, and seconds?

T. The first of these divisions was introduced by Divine authority; the second class was invented for the convenience of mankind. There is, however, another division of time marked out by nature.

C. What is that, sir?

T. The length of the *month;* not, indeed, that month which consists of four weeks, nor that by which the year is divided into 12 parts. These are both arbitrary. But by a month was originally meant the time which the moon takes in performing her journey round the earth.

J. How many days does the moon take for this purpose?

T. If you refer to the time in which the moon revolves from one point of the heavens to the same point again, it consists of 27 days, 7 hours, and 43 minutes; this is called the *periodical* month: but if you refer to the time passed from new moon to

new moon again, the month consists of 29 days, 12 hours, and 44 minutes; this is called the *synodical* month.

C. Pray explain the reason of this difference.

T. It is occasioned by the earth's annual motion in its orbit. Let us refer to our watch as an example. The two hands are together at 12 o'clock; now, when the minute-hand has made a complete revolution, are they together again?

J. No; for the hour-hand is advanced the twelfth part of its revolution, which, in order that the other may overtake, it must travel five minutes more than the hour.

T. And something more; for the hour-hand does not wait at the figure 1 till the other comes up: and therefore they will not be together till between 5 and 6 minutes after one.

Now apply this to the earth and moon. Suppose S to be the sun; T the earth, in a part of its orbit Q L; and E to be the

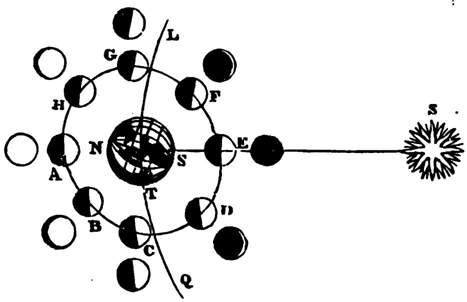


Fig. 11.

position of the moon. If the earth had no motion, the moon would move round its orbit E H C into the position E again, in 27 days, 7 hours, 43 minutes; but while the moon is describing her journey, the earth has passed through nearly a twelfth part of its orbit, which the moon must also describe before the two bodies come again into the same position that they before held with respect to the sun. This takes up so much more time as to make her synodical month equal to 29 days, 12 hours, and 44 minutes: hence the foundation of the division of time into months.

We will now proceed to describe some other particulars relating to the moon, as a body depending, like the earth, on the sun for her light and heat.

C. Does the moon shine with a borrowed light only?

T. This is certain; for otherwise, if, like the sun, she were a luminous body, she would always shine with a full orb as the sun does. Her diameter is nearly 2200 miles.

J. And I remember she is at the distance of 240,000 miles from the earth.

T. The sun S (in the last fig.) always enlightens one-half of the moon E; and its whole enlightened hemisphere, or a part of it, or none at all, is seen by us according to her different positions in the orbit with respect to the earth; for only those parts of the enlightened half of the moon are visible at T which are cut off by, and are *within*, the orbit.

J. Then when the moon is at E, no part of its enlightened side is visible to the earth?

T. You are right; it is then *new* moon, or *change;* for it is usual to call it new moon the first day it is visible to the earth, which is not till the second day after the change. And the moon being in a line between the sun and earth, they are said to be in *conjunction*.

C. And at A, all the illuminated hemisphere is turned to the earth.

T. This is called *full* moon; and the earth being between the sun and moon, they are said to be in *opposition*. The enlightened parts of the little figures on the outside of the orbit represent the appearance of the moon as seen by a spectator on the earth.

C. But if the earth is *between* the sun and the moon, how can the latter be enlightened by the sun?

T. Although between, it is not often in a direct line between. It is at most times of full moon, above or below the line; when in a direct line, or partly so, there is an eclipse, as I shall presently explain.

J. Is the little figure, then, opposite E wholly dark to show that the moon is invisible at *change?*

T. It is; and when it is at F, a small part of the illuminated hemisphere is *within* the moon's orbit, and therefore to a spectator on the earth it appears *horned;* at G one-half of the enlightened hemisphere is visible, and it is said to be in *quadrature;* at H three-fourths of the enlightened part is visible to the earth, and it is then said to be *gibbous;* and at A the whole enlightened face of the moon is turned to the earth, and it is said to be *full*. The same may be said of the rest.

The horns of the moon, before conjunction or new moon, are turned to the *east;* after conjunction they are turned to the *west*.

C. I see the figure is intended to show that the moon's orbit is elliptical: does she also turn upon her axis?

T. She does; and she requires the same time for her diurnal rotation as she takes in completing her revolution about the earth; and consequently, though every part of the moon is successively presented to the sun, yet the same hemisphere is always turned to the earth. This is known by observation with good telescopes.

J. Then the length of a day and night in the moon is equal to more than 29 days and a half of ours?

T. It is so: and therefore, as the length of her year, which is measured by her journey round the sun, is equal to that of ours, she can have but about twelve days and one third in a year. Another remarkable circumstance relating to the moon is, that the hemisphere next the earth is never in darkness; for in the position E, when it is turned from the sun, it is illuminated by light reflected from the earth, in the same manner as we are enlightened by a full moon. But the other hemisphere of the moon has a fortnight's light and darkness by turns.

C. Can the earth, then, be considered as a satellite to the moon?

T. It would, perhaps, be inaccurate to denominate the larger body a satellite to the smaller: but, with regard to affording reflected light, the earth is to the moon what the moon is to the earth, and subject to the same changes of horned, gibbous, full, &c.

C. But it must appear much larger than the moon.

T. The earth will appear, to the inhabitants of the moon, about 13 times as large as the moon appears to us. When it is *new moon* to us, it is *full earth* to them, and the reverse.

J. Is the moon then inhabited as well as the earth?

T. Though we cannot demonstrate this fact, yet there are many reasons to induce us to believe it; for the moon is a secondary planet of considerable size;—its surface is diversified like that of the earth with mountains and valleys;—the former have been measured by Dr. Herschel, and some of them found to be about a mile in height. The situation of the moon, with respect to the sun, is much like that of the earth; and by rotation on her axis, and a small inclination on that axis to the plane of her orbit, she enjoys, though not a considerable, yet an agreeable variety of day and night and of seasons. To the moon, our globe appears a capital satellite, undergoing the same changes of illumination as the moon does to the earth. The sun and stars rise and set there as they do here, and heavy bodies will fall on the moon as they do on the earth. Dr. Herschel

discovered some years ago three volcanoes, all burning, in the moon; two of them appeared to him nearly extinct, but the third showed an actual eruption of fire or luminous matter. He thought the eruption resembled a small piece of burning charcoal when it is covered by a thin coat of white ashes, which frequently adhere to it when it has been ignited some time. But no large seas or tracts of water have been observed in the moon, nor is the existence of a lunar atmosphere certain. Therefore, if she has inhabitants, they must materially differ from those who live upon the earth.

CONVERSATION XV.

Of Eclipses.

C. Will you, sir, explain to us the nature and causes of eclipses?

T. I will, with great pleasure. You must observe, then, that eclipses depend upon this simple principle, that all opaque bodies, when exposed to any light, cast a shadow behind them.

J. The earth, being a body of this kind, must cast a very large shadow on the side opposite to the sun.

T. It does; and an eclipse of the moon happens when the earth T passes between the sun S and the moon M; for then the earth's shadow is cast on the moon.

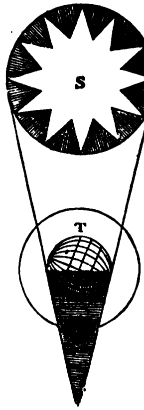


Fig. 12.

C. When does this happen?

T. It is only when the moon is full, or in *opposition*, that it can come within the shadow of the earth.

J. Eclipses of the moon, however, do not happen every time it is full: what is the reason of this?

T. Because the orbit of the moon does not coincide with the plane of the earth's orbit, but one half of it is elevated about five degrees and a third above it, and the other half is as much below it: and therefore, unless the full moon happen in or near one of the nodes, that is, in or near the points in which the two orbits intersect each other, she will pass above or below the shadow of the earth, in which case there will be no eclipse.

C. What is the greatest distance from the node, at which an eclipse of the moon can happen?

T. There can be no eclipse, if the moon, at the time when she is full, be more than twelve degrees from the node: when she is within that distance, there will be a *partial* or *total* eclipse, according as a part, or the whole disc or face of the moon, falls within the earth's shadow. If the eclipse happen exactly when the moon is full in the node, it is called a central eclipse.

J. I suppose the duration of the eclipse lasts all the time that the moon is passing through the shadow.

T. It does: and you observe that the shadow is considerably wider than the moon's diameter; and therefore an eclipse of the moon lasts sometimes three or four hours. The shadow also, you perceive, is of a conical shape, and consequently, as the moon's orbit is an ellipse and not a circle, the moon will, at different times, be eclipsed when she is at different distances from the earth.

C. And, according as the moon is nearer to, or farther from the earth, the eclipse will be of a greater or less duration: for the shadow being conical becomes less and less, as the distance from the body by which it is cast is greater.

T. It is by knowing exactly at what distance the moon is from the earth, and of course the width of the earth's shadow at that distance, that all eclipses are calculated with considerable accuracy, for many years before they happen. Now it is found that, in all eclipses, the shadow of the earth is conical, which is a demonstration, that the body by which it is projected is of a spherical form, for no other sort of figure would, in *all positions*, cast a conical shadow. This is mentioned as another proof, that the earth is a spherical body.

J. It seems to prove another thing, viz. that the sun must be a larger body than the earth.

T. Your conclusion is just; for if the two bodies were equal to one another the shadow would be cylindrical; and if the earth were the larger body, its shadow would be of the figure of a cone, which had lost its vertex, and the farther it were extended the larger it would become. In either case the shadow would run out to infinite space, and accordingly must sometimes involve in it the other planets, and eclipse them, which is contrary to fact. Therefore, since the earth is neither larger than, nor equal to the sun, it must be the lesser body. We will now proceed to the eclipses of the sun.

Fig. 13.

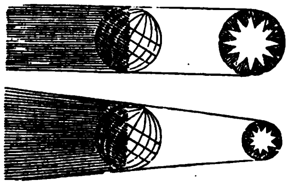


Fig. 14.

C. How are these occasioned?

T. An eclipse of the sun happens when the moon M, passing between the sun S and the earth T, intercepts the sun's light, and hinders it from coming to the earth.

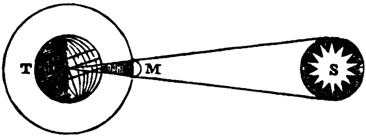


Fig. 15.

J. The sun then can be eclipsed only at the new moon?

T. Certainly; for it is only when the moon is in *conjunction* that it can pass directly between the sun and earth.

C. Is it only when the moon at her conjunction is near one of its nodes, that there can be an eclipse of the sun?

T. An eclipse of the sun depends upon this circumstance: for unless the moon is in or near one of its nodes, she cannot appear in the same place with the sun, or seem to pass over his disc. In every other part of the orbit, she will appear above or below the sun. If the moon be *in* one of the nodes, she will, in most cases, cover the whole disc of the sun, and produce a *total* eclipse: if she be anywhere within about 16 degrees of a node, a *partial* eclipse will be produced.

The sun's diameter is supposed to be divided into 12 equal parts, called *digits*, and in every partial eclipse, as many of these parts of the sun's diameter as the moon covers, so many digits are said to be eclipsed.

J. I have heard of *annular* eclipses; what are they, sir?

T. When a ring of light appears round the edge of the moon during an eclipse of the sun, it is said to be annular, from the Latin word *annulus*, a *ring*: this kind of eclipse is occasioned by the moon being at her greatest distance from the earth at the time of an eclipse; beeause, in that situation, the vertex, or tip of the cone of the moon's shadow, does not reach the surface of the earth.

C. How long can an eclipse of the sun last?

T. A total eclipse of the sun is a very curious and uncommon spectacle; and total darkness cannot last more than three or four minutes. Some good observations of a total eclipse were made on July 8. 1842. M. Arago collected them from various quarters, and published a very instructive memoir on the subject.

C. I should like to hear what he says of the effect of the darkness.

T. In some places convolvulus and other flowers closed during the eclipse. The darkness was not total; and objects presented a livid greenish appearance. A dog, to whom bread was thrown, ceased eating it, as soon as the eclipse became total; another dog took refuge between his master's legs; horses, oxen, and asses stopped suddenly when the darkness came; fowls left their food and retired to roost; a hen gathered her young beneath her wings; ducks fled toward the bank; ants even stopped their course, and did not continue journeying on until the sun again appeared; bats and owls came from their retreats, as if it were night; swallows disappeared; birds ceased to sing; and bees returned to their hives.

C. If I were unaware of the approach of an eclipse, I think I should feel very much alarmed at the unusual darkness.

T. There was a child just in such a predicament; he was tending a flock in the Alps, and to his horror, he saw the sun gradually losing its brightness, and no cloud near. When all the light had gone, he burst into tears, and called for help: but when he again saw the light returning, he crossed his hands, and cried out, "Oh, beautiful sun!"

C. I remember on July 28th, 1851, there was a total eclipse of the sun; and not being total here, I heard that astronomers went to distant places in order to observe it. What made them so curious? From the nearly total eclipse in England, I should have thought they could have judged of the quite total.

T. There you are greatly wrong. Independently of the physical phenomena of nature which attend a total eclipse, there were certain rose-coloured prominences and certain beads of light, and also the halo or corona, that had been observed in the previous total eclipse on July 8th, 1842, and which required further examination.

C. And were these previous observations confirmed?

T. The rose-coloured prominences were seen by all observers, and were found for the most part to be conical and of greater height than breadth. Mr. Lassell took his station at Trollhätten Falls, and describes them as of a brilliant lake colour, and quite defined and hard, and evidently forming part of the sun. Mr. Carrington, at Gota River, found four of them. Two were in shape like hay-cocks, and were pink tinged with white. The appearance of one of the others was like a mighty flame bursting through the roof of a house, and blown by a strong wind. The Astronomer Royal, who stationed himself near Gottenberg, was much struck by the remarkable appearance of these flames.

C. And were the beads seen? and what are they?

T. These were not seen by some observers, but were by others. Just before the eclipse became total, the line of light, which yet remained of the sun, became broken into a series of bright spots, like beads of light, some larger than the others; and the same occurred at the termination of the eclipse, when the first indication of the returning sun was a series of bright spots, which gradually melted into each other and formed a line of light. They are called Baily's beads. By some they are thought to be an ocular deception.

C. Did it become totally dark?

T. Some observers found it more dark than others; which may be due to their different physical constitutions. The corona was there, which Mr. Lassell conceived to give as much light as the full moon. The moon, as it appeared obscuring the sun, presented a jagged appearance at its edges. The darkness was of a very unearthly character, and appears to have impressed the

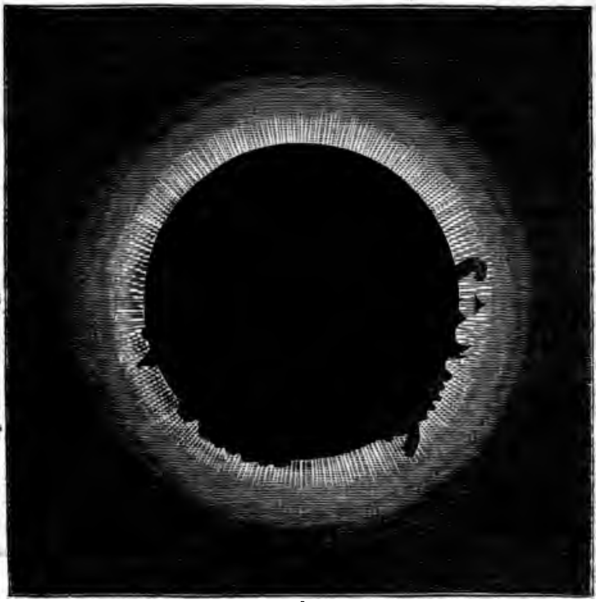


Fig. 16.

observers with awe. There was a livid look about all nature. The quick transition from broad daylight to the darkness of night was a thing to which the organs of sight had not been trained. And if the astronomers were affected thus, you cannot be surprised to hear of the terror which took possession of the natives, who were taken by surprise at this to them supernatural event. I should have told you that while the least part of the sun remains, there is much light; and the transition to darkness, when all is obscured, is sudden.

Mr. Dawes, who observed the eclipse at Ravelsberg (lat. 56° 16′ N.; lon. 51′ 33″ E.), the same place with Mr. Hind, but independently, has given a sketch of the red prominences, which I have represented in fig. 16. The shaded appendages on the border of the sun show their position and shape. I have also added the halo, as given by M. Arago for the eclipse in 1842, and which seems to have presented a similar appearance in this case.

CONVERSATION XVI.

Of the Tides.

T. We will proceed to the consideration of the *Tides*, or the ebbing and flowing of the ocean.

J. Is this subject connected with astronomy?

T. It is, inasmuch as the tides are occasioned by the attraction of the sun and moon upon the waters, but more particularly by that of the latter. You will readily conceive that the tides are dependent upon some known and determinate laws, because you have seen in White's Ephemeris, that the exact time of high water at London bridge on the morning and afternoon of every day in the year is set down.

C. I have frequently wondered how this could be known with such a degree of accuracy: but I am told there is hardly a waterman that plies at the stairs but can readily tell when it will be high water.

T. The generality of the watermen are probably as ignorant as yourself of the cause by which the waters flow and ebb; but by experience they know that the time of high water differs on each day about three quarters of an hour, or a little more or less, and therefore, if it be high water to-day at six o'clock, they will at a guess tell you, that to-morrow the tide will not be up till a quarter before seven.

J. Will you explain the causes?

T. You must bear in your mind, then, that the tides are occa-

sioned by the attraction of the sun and moon upon the waters of the earth: perhaps a diagram may be of some assistance to you. Let A p T n be supposed the earth, C its centre: let the dotted

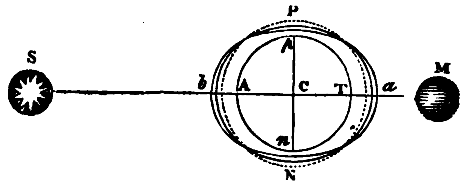


Fig. 17.

circle represent a mass of water covering the earth: let M be the moon in its orbit, and S the sun.

Since the force of gravity or attraction diminishes as the squares of the distance increase*, the waters on the side T are more attracted by the moon M, than the central parts at C; and the central parts are more attracted than the waters at A; consequently the waters at A will recede from the centre; therefore while the moon is in the situation M, the waters will rise towards *a* and *b* on the opposite sides of the earth.

C. You mean that the waters will rise at *a* by the immediate attraction of the moon M, and will rise at *b* by the centre C receding and leaving them more elevated there.

T. That is the explanation. It is evident that the quantity of water being the same, a rise cannot take place at *a* and *b*, without the parts at P and N being at the same time depressed.

J. In this situation the water may be considered as assuming a spheroidal shape.

T. If the earth and moon were without motion, and the earth covered all over with water, the attraction of the moon would raise it up in a heap in that part of the ocean to which the moon is vertical, and there it would always continue; but, by the rotation of the earth on its axis, each part of its surface, to which the moon is vertical, is presented twice a day to the action of the moon, and thus are produced two floods and two ebbs.

C. How twice a day?

T. In the position of the earth and moon as it is in our figure, the waters are raised at T by the direct attraction of the moon, and a tide is accordingly produced; but when, by the earth's rotation, T comes, 12 hours afterwards, into the position A, another tide is occasioned by the receding of the waters there from the centre.

* See Mechanics, Conversation VII.

J. You have told us that the tides are produced in those parts of the earth to which the moon is vertical; but this effect is not confined to those parts?

T. It is not; but there the attraction of the moon has the greatest effect: in all other parts her force is weaker, because it acts in a more oblique direction.

C. Are there two tides in every 24 hours?

T. If the moon were stationary this would be the case; but because that body is also proceeding every day about 13 degrees from west to east in her orbit, the earth must make more than one revolution on its axis before the same meridian is in conjunction with the moon, and hence two tides take place in about 24 hours and 50 minutes.

J. But I remember when we were at the sea-side, that the tides rose higher at some seasons than at others: how do you account for this?

T. The moon goes round the earth in an elliptic orbit; and, therefore, she approaches nearer to the earth in some parts of her orbit than in others. When she is nearest, the attraction is the strongest, and consequently it raises the tides most; and when she is farthest from the earth, her attraction is the least, and the tides the lowest.

J. Do they rise to different heights in different places?

T. They do: in the Black Sea and the Mediterranean the tides are scarcely perceptible. At the mouth of the Indus, the water rises and falls full 30 feet. The tides are remarkably high on the coast of Malay, in the Straits of Sunda, in the Red Sea, along the coasts of China, Japan, &c. In general, the tides rise highest and strongest in those places that are narrowest.

C. You said the sun's attraction occasioned tides as well as that of the moon.

T. It does; but owing to the immense distance of the sun from the earth, it produces but a small effect in comparison of the moon's attraction. Sir Isaac Newton computed, that the force of the moon raised the water in the great ocean 10 feet, whereas that of the sun raised it only 2 feet. When both the attraction of the sun and moon act in the same direction, that is, at new and full moon, the combined forces of both raise the tide 12 feet. But when the moon is in her quarters, the attraction of one of these bodies raises the water, while that of the other depresses it; and, therefore, the smaller force of the sun must be subtracted from that of the moon; consequently the tides in the midst of the ocean will be no more than 8 feet. The highest tides are called spring tides, and the lowest are denominated neap tides.

J. I understand that, in the former case, the height to which the tides are raised must be calculated by *adding* together the attractions of the sun and moon; and in the latter, it must be estimated by the *difference* of those attractions.

T. You are right. When the sun and moon are both vertical to the equator of the earth, and the moon at her least distance from the earth, then the tides are highest.

C. Do the highest tides happen at the equinoxes?

T. Strictly speaking, these tides do not happen till some little time after, because in this, as in other cases, the actions do not produce the greatest effect when they are at the strongest, but some time afterwards; thus the hottest part of the day is not when the sun is on the meridian, but between two and four o'clock in the afternoon. Another circumstance must be taken into consideration; the sun being nearer to the earth in winter than in summer, it is of course nearer to it in February and October than in March and September; and therefore, all these things being put together it will be found that the greatest tides happen a little before the vernal and some time after the autumnal equinoxes. The probable times of the greatest tides in each year are given in White's Ephemeris.

J. Since the attraction of the moon has a greater effect in producing the tides than that of the sun, it is natural to conceive that the magnitude of the tides varies with the distance of the moon from the earth.

T. You are perfectly right in that conjecture. The moon's attraction upon the waters is greatest when she is in her *perigee* or nearest the earth; and it is least when she is in her *apogee*, or the point farthest from the earth. The tides are proportionally greater in the former case than in the latter. The moon's attraction is also greatest, all other things being the same, when she is in the equator. The moon's declination always has an effect, more or less, in retarding the actual time of high water. Tables are given in several books of astronomy and navigation, by means of which the time of high water may be accurately computed for any assigned place, for any particular declination, and for the various positions with regard to the moon's distance from the earth.

CONVERSATION XVII.

Of the Harvest Moon.

T. From what we said yesterday, you will easily understand why the moon rises about three quarters of an hour later every day than on the one preceding.

C. It is owing to the daily progress which the moon is making in her orbit, on which account any meridian on the earth must make more than one complete rotation on its axis, before it comes again into the same situation with respect to the moon that it had before. And you told us that this occasioned a difference of about 50 minutes.

T. At the equator this is generally the difference of time between the rising of the moon on one day and the preceding. But in places of considerable latitude, as that in which we live, there is a remarkable difference about the time of harvest, when at the season of full moon she rises for several nights together only about 20 minutes later on the one day than on that immediately preceding. By thus succeeding the sun before the twilight is ended, the moon prolongs the light, to the great benefit of those who are engaged in gathering in the fruits of the earth; and hence the full moon at this season is called the harvest moon. It is believed that this was observed by persons engaged in agriculture, at a much earlier period than it was noticed by astronomers; the former ascribed it to the goodness of the Deity, not doubting but that he had ordered it so on purpose for their advantage.

J. But the people at the equator do not enjoy this benefit.

T. Nor is it necessary that they should; for in those parts of the earth the seasons vary but little, and the weather changes but seldom, and at stated times; to them, then, moonlight is not wanting for gathering the fruits of the earth.

C. Can you explain how it happens, that the moon at this season of the year rises one day after another with so small a difference of time?

T. With the assistance of a globe I could at once clear the matter up. But I will endeavour to give you a general idea of the subject without that instrument. That the moon loses more time in her risings when she is in one part of her orbit, and less in another, is occasioned by the moon's orbit lying sometimes more oblique to the horizon than at others.

J. But the moon's path is not marked on the globe.

T. It is not; you may, however, consider it, without much error, as coinciding with the ecliptic. And in the latitude of London, as much of the ecliptic rises about *Pisces* and *Aries* in two hours as the moon goes through in six days; therefore, while the moon is in these signs, she differs but two hours in rising for six days together, that is, one day with another, about 20 minutes later every day than on the preceding.

C. Is the moon in those signs at the time of harvest?

T. In August and September you know that the sun appears

in Virgo and Libra, and, of course, when the moon is *full*, she must be in the opposite signs, viz. *Pisces* and *Aries*.

C. Will you explain, sir, how it is that the people at the equator have no harvest moon?

T. At the equator, the north and south poles lie in the horizon, and therefore the ecliptic makes the same angle with the horizon when Aries rises, as it does northward when Libra rises; but as the harvest moon depends upon the different angles at which different parts of the ecliptic rise, it is evident there can be no harvest moon at the equator.

The farther any place is from the equator, if it be not beyond the polar circles, the angle, which the ecliptic makes with the horizon, when Pisces and Aries rise, gradually diminishes, and, therefore, when the moon is in these signs, she rises with a nearly proportionable difference later every day than on the former, and this is more remarkable about the time of full moon.

J. Why have you excepted the space on the globe beyond the polar circles?

T. At the polar circles, when the sun touches the summer tropic, he continues 24 hours above the horizon, and 24 hours below it when he touches the winter tropic. For the same reason, the full moon neither rises in the summer, when she is not wanted, nor sets in the winter, when her presence is so necessary. These are the only two full moons which happen when the sun is in the tropics, for all the others rise and set. In summer the full moons are low, and their stay above the horizon short; in winter they are high, and stay long above the horizon. A wonderful display this of the Divine wisdom and goodness, in apportioning the quantity of light, suitable to the various necessities of the inhabitants of the earth, according to their different situations.

C. At the poles the matter is, I suppose, still different.

T. There one half of the ecliptic never sets, and the other half never rises; consequently, the sun continues one half year above the horizon, and the other half below it. The full moon, being always opposite to the sun, can never be seen by the inhabitants of the poles, while the sun is above the horizon. But all the time that the sun is below the horizon, the full moon never sets. Consequently, to them the full moon is never visible in their summer; and in their winter they have it always before and after the full, shining for 14 of our days and nights without intermission. And when the sun is depressed the lowest under the horizon, then the moon ascends with her highest altitude.

J. This indeed exhibits in a high degree the attention of Providence to all his creatures. But if I understand you, the in-

habitants of the poles have in their winter a fortnight's light and darkness by turns?

T. This would be the case for the whole six months that the sun is below the horizon, if there were no refraction*, and no substitute for the light of the moon. But by the atmosphere's refracting the sun's rays, he becomes visible a fortnight sooner, and continues a fortnight longer in sight, than he would do, were there no such property belonging to the atmosphere. And in those parts of the winter, when it would be absolutely dark in the absence of the moon, the brilliancy of the *Aurora Borealis* is probably so great as to afford a very comfortable degree of light. Mr. Hearne, in his travels near the polar circle, has this remark in his journal: "December 24. The days were so short, that the sun only took a circuit of a few points of the compass above the horizon, and did not, at its greatest altitude, rise half way up the trees. The brilliancy of the Aurora Borealis, however, and of the stars, even without the assistance of the moon, made amends for this deficiency, for it was frequently so light all night, that I could see to read a small print."

CONVERSATION XVIII.

Of Mercury.

T. Having fully described the earth and the moon, the former a primary planet, and the latter its attendant satellite, we shall next consider the other planets, in their order, with which, however, we are less interested.

Mercury, you recollect, is the planet nearest the sun; and Venus is the second in order. These are called inferior planets.

C. Why are they thus denominated?

T. Because they both revolve in orbits which are included *within* that of the earth; thus in the diagram of the solar system (fig. 2.), Mercury makes his annual journey round the sun in the orbit *a*; Venus in *b*; and the earth, farther from that luminary than either of them, makes its circuit in *t*.

J. How is this known?

T. By observation: for by attentively watching the progress of these bodies, it is found that they are continually changing their places among the fixed stars, and that they are never seen in opposition to the sun, that is, they are never seen in the western side of the heavens in the morning, when he appears in

* The subject of Refraction will be very particularly explained when we come to Optics.

the east; nor in the eastern part of the heavens in the evening, when the sun appears in the west.

C. Then they may be considered as attendants upon the sun?

T. They may: Mercury is never seen from the earth at a greater distance from the sun than about 28 degrees, or about as far as the moon appears to be from the sun on the second day after its change; hence it is that we so seldom see him; and when we do, it is for so short a time, and always in twilight, that sufficient observations have not been made to ascertain whether he has diurnal motion on his axis.

J. Would you then conclude he has such a motion?

T. I think we ought; because it is known to exist in all those planets, upon which observations of sufficient extent have been made; and, therefore, we may surely infer, without much probability of error, that it belongs also to Mercury.

C. At what distance is Mercury from the sun?

T. He revolves round that body at about 37 millions of miles distance, in 88 days nearly; and therefore you can now tell me how many miles he travels in an hour.

J. I can; for supposing his orbit circular, I must multiply the 37 millions by 6*; which will give 222 millions of miles for the length of his orbit; this I shall divide by 88, the number of days he takes in performing his journey, and the quotient resulting from this must be divided by 24, for the number of hours in a day; and by these operations I find that Mercury travels at the rate of more than 105,000 miles in an hour.

T. By turning to page 26 and 27 of the Ephemeris, you will find the place of Mercury for every fourth day; and also his time of rising, southing, and setting.

C. How large is Mercury?

T. He is the smallest of all the planets, his diameter being only something more than 3200 miles.

J. But his situation being so much nearer to the sun than ours, he must enjoy a considerably greater share of its heat and light.

T. So much so, as would indeed infallibly burn everything belonging to the earth to atoms, were she similarly situated. The heat of the sun, at Mercury, must be 7 times greater than our summer heat.

C. And do you imagine that, thus circumstanced, this planet can be inhabited?

T. Not by such beings as we are: you and I could not long

* Or, to be more correct, multiply by 6·832. See p. 4.

exist at the bottom of the sea; yet the sea is the habitation of millions of living creatures: why then may there not be inhabitants in Mercury, fitted for the enjoyment of the situation which that planet is calculated to afford? If there be not, we must be at a loss to know why such a body was formed: certainly it could not be intended for our benefit, for it is rarely even seen by us.

CONVERSATION XIX.

Of Venus.

T. We now proceed to Venus, the second planet in the order of the solar system, but by far the most beautiful of them all.

J. How far is Venus from the sun?

T. That planet is 68 millions of miles from the sun, and she finishes her journey in 224¾ days; consequently she must travel at the rate of 75,000 miles in an hour.

C. Venus is larger than Mercury, I dare say?

T. Yes, she is nearly as large as the earth, which she resembles also in other respects, her diameter being about 7700 miles, and she has a rotation about her axis in 23 hours and 20 minutes. The quantity of light and heat which she enjoys from the sun must be double that which is experienced by the inhabitants of this globe.

J. Is there also a difference in her seasons, as there is here?

T. Yes, in a much more considerable degree. The axis of Venus inclines about 75 degrees, but that of the earth inclines only 23 degrees; and as the variety of the seasons in every planet depends on the degree of the inclination of the axis, it is evident that the seasons must vary more with Venus than with us.

C. Venus appears to us larger sometimes than at others.

T. She does; and the great variations of the apparent diameter of Venus demonstrate that her distance from the earth is exceedingly variable. It is the largest when the planet passes over the disc of the sun; that is, as we shall soon see, when there is a transit. Suppose S to be the sun, T the earth in her orbit, and *a*, *b*, *c*, *d*, *e*, *f*, Venus in hers; now it is evident that when Venus is at *a*, between the sun and the earth, she would, if visible, appear much larger than when she is at *d* in opposition.

J. That is because she is so much nearer in the former case than in the latter, being in the situation *a* but 27 millions of miles from the earth T, but at *d* she is 163 millions of miles off.

T. Now, as Venus passes from *a*, through *b*, *c*, to *d* she may be observed, by means of a good telescope, to have all the same phases as the moon has in passing from new to full; therefore when she is at *d* she is full, and is seen among the fixed stars: during her journey from *d* to *e*, she proceeds with a *direct* motion in her orbit, and at *e* she will appear to an inhabitant of the earth, for a few days, to be *stationary*, not seeming to change her place among the fixed stars, for she is coming towards the earth in a direct line: but in passing from *e* to *f*, though still with a direct motion, yet to a spectator at T, her course will seem to be back again, or *retrograde*, for she will seem to have gone back from *z* to *y*; her path will appear retrograde till she gets to *c*, when she will again appear *stationary*, and afterwards from *c* to *d*, it will be *direct* among the fixed stars.

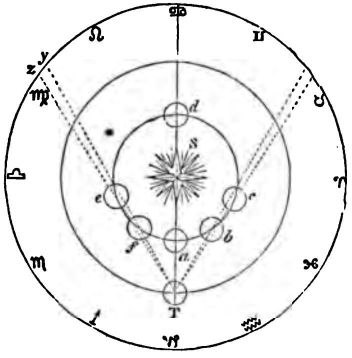


Fig. 16.

C. When is Venus an evening and when a morning star?

T. She is an evening star all the while she appears *east* of the sun, and a morning star while she is seen *west* of him. When she is at *a* she will be invisible, her dark side being towards us, unless she be exactly in the node, in which case she will pass over the sun's face like a little black spot.

J. Is that called the transit of Venus?

T. It is; and it happens twice only in about 120 years. By this phenomenon astronomers have been enabled to ascertain with great accuracy the distance of the earth from the sun; and, having obtained this, the distances of the other planets are easily found. By the two transits which happened in 1761 and 1769, it was clearly demonstrated, that the mean distance of the earth from the sun was between 95 and 96 millions of miles.

The next transit of Venus will be in December, 1874.

C. How do you find the distances of the other planets from the sun, by knowing that of the earth?*

* The remainder of this Conversation may be omitted by those young persons who are not expert in arithmetical operations. The author, however, knows from experience that children may, at a very early age, be brought to understand these higher parts of arithmetic.

T. I will endeavour to make this plain to you. Kepler, a great astronomer, discovered that all the planets are subject to one general law, which is, that the *squares of their periodical times are proportional to the cubes of their distances from the sun.*

J. What do you mean by the *periodical times?*

T. I mean the times which the planets take in revolving round the sun; thus the periodical time of the earth is 365¼ days; that of Venus 224¾ days; that of Mercury 88 days.

C. How then would you find the distance of Mercury from the sun?

T. By the rule of three: I would say as the square of 365 days (the time which the earth takes in revolving about the sun) is to the square of 88 days (the time in which Mercury revolves about the sun), so is the cube of 95 millions (the distance in miles of the earth from the sun) to a fourth number.

C. I am aware that a number multiplied by itself is a *square;* and multiplied twice by itself is a *cube.* So, if you will allow me, I will square and cube the figures as you have expressed them. 365 squared is 133,225; 88 squared is 7744; and 95 cubed is 857,375.

T. The proportion is thus expressed; as 133,225 is to 7744 so is 857,375 to the number required. If you work that as a rule of three sum, by multiplying together the last two sums and dividing by the first, you will get 49,836.

J. And is that the distance of Mercury from the sun?

T. No; it is, as I told you, the cube of the distance; the cube root of this, which is nearly 37, is the distance in millions of miles. You will find 37 twice multiplied by itself to be a little over this number.

C. Does Venus turn round on her axis?

T. From the movement of certain spots upon the surface of the planet it has been concluded that she revolves about her axis once in 24 hours.

CONVERSATION XX.

Of Mars.

T. Next to Venus is the earth and her satellite, the moon; but of these sufficient notice has already been taken; and, therefore, we shall pass on to the planet Mars, which is known in the heavens by a dusky red appearance. Mars, together with Jupiter, Saturn, and Herschel, are called superior planets, because they are outside the orbit of the earth.

C. At what distance is Mars from the sun?

T. About 144 millions of miles; the length of his year is equal to 687 of our days; and, therefore, he travels at the rate of more than 53 thousand miles in an hour: his diurnal rotation on his axis is performed in 24 hours and 39 minutes, which makes his figure that of an oblate spheroid.

J. How is the diurnal motion of this planet discovered?

T. By means of a very large spot, which is seen distinctly on his face, when he is in that part of his orbit which is opposite to the sun and earth.

C. Is Mars as large as the earth?

T. No: his diameter is only 4189 miles, which is but little more than half that of the earth. And, owing to his distance from the sun, he will not enjoy one half of the light and heat which we have.

J. And yet, I believe, he has not the benefit of a moon?

T. No moon has ever been discovered belonging either to Mercury, Venus, or Mars.

C. Do the superior planets exhibit similar appearances of direct and retrograde motion to those of the inferior planets?

T. They do: suppose *s* the sun; *a*, *b*, *d*, *f*, *g*, *h*, the earth in different parts of its orbit, and *m* Mars in his orbit. When the earth is at *a*, Mars will appear among the fixed stars at *x*; when by its annual motion the earth has arrived at *b*, *d*, and *f*, respectively, the planet Mars will appear in the heavens at *y*, *z*, and *w*: when the earth has advanced to *g*, Mars will appear stationary at *o*: to the earth, in its journey from *g* to *h*, the planet will seem to go backwards or retrograde in the heavens from *o* to *z*, and this retrograde motion will be apparent till the earth has arrived at *a*, when the planet will again appear stationary.

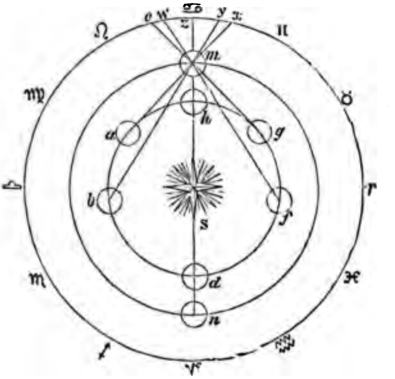


Fig. 19.

J. I perceive that Mars is retrograde when in *opposition*; the same is, I suppose, applicable to the other superior planets; but

the retrograde motion of Mercury and Venus is when those planets are in *conjunction*.

T. You are right: and you see the reason, I dare say, why the superior planets may be in the west in the morning when the sun rises in the east, and the reverse.

C. For when the earth is at *d*, Mars may be at *n*, in which case the earth is between the sun and the planet. I observe also that the planet Mars, and consequently the other superior planets, are much nearer the earth at one time than at others.

T. The difference with respect to Mars is no less than 190 millions of miles, the whole length of the orbit of the earth. And on this account it was that during the latter part of the year 1845 he appeared to the naked eye almost as large as Jupiter.

J. You promised to explain, when you came to speak of the planets, the meaning of the word heliocentric.

T. It is a term used to express the place of the heavenly body, as seen from the centre of the sun; whereas the *geocentric* place of a planet is the position which it has when seen from the centre of the earth.

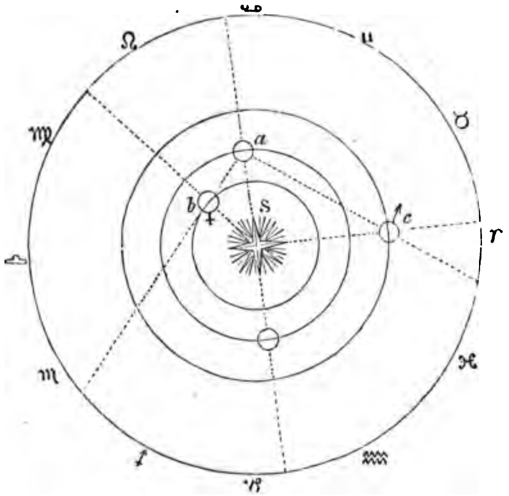


Fig. 20.

C. Will you show us by a figure in what this difference consists?

T. I will: let s represent the place of the sun, *b* Venus in its orbit, *a* the earth in hers, and *c* Mars in his orbit; and the outermost circle will represent the sphere of fixed stars. Now, to a spectator on the earth *a*, Venus will appear among the fixed stars in the beginning of Scorpio, but, as viewed from the sun, she will be seen beyond the middle of Leo. Therefore the *geocentric* longitude of Venus will be in Scorpio, but her *heliocentric* longitude will be in Leo. Again, to a spectator at *a*, the planet Mars at *c* will appear among the fixed stars towards the end of the sign of Pisces; but, as viewed from the sun, he will be seen at the beginning of the sign Aries: consequently the *geocentric* longitude of Mars is in Pisces; but his *heliocentric* longitude is then in Aries.

CONVERSATION XXI.

Of Jupiter.

T. We now come to Jupiter, the largest of all the planets, which is easily known by his peculiar magnitude and brilliancy.

C. Is Jupiter larger than Venus?

T. Though he does not appear so large, yet the magnitude of Venus bears but a very small proportion to that of Jupiter, whose diameter is 90,000 miles; his bulk exceeds the bulk of Venus 1500 times: his distance from the sun is estimated at more than 490 millions of miles.

J. Then he is *five* times farther from the sun than the earth; and, consequently, as light and heat diminish in the same proportion as the squares of the distances from the illuminating body increase, the inhabitants of Jupiter enjoy but a twenty-fifth part of the light and heat of the sun that we enjoy.

T. Another thing remarkable in this planet is, that it revolves on its axis, which is perpendicular to its orbit, in 10 hours; and, in consequence of this swift and diurnal rotation, his equatorial diameter is 6000 miles greater than his polar diameter.

C. Since then a variety in the seasons of a planet depends upon the inclination of the axis to its orbit, and since the axis of Jupiter has no inclination, there can be no difference in his seasons, nor any in the length of his days and nights.

T. You are right: his days and nights are always five hours each in length; and at his equator, and its neighbourhood, there is perpetual summer; and an everlasting winter reigns in the polar regions.

J. What is the length of his year?

T. It is equal to nearly 12 of ours, for he takes 11 years, 314 days, and 20 hours to make a revolution round the sun; consequently he travels at the rate of more than 28,000 miles in an hour.

This noble planet is accompanied by four satellites, which revolve about him, at different distances, and in different periodical times: the *first* in about 1 day and 18 hours; the *second* in 3 days 13 hours; the *third* in 7 days 3 hours; and the *fourth* in 16 days and 16 hours.

C. And are these satellites, like our moon, subject to be eclipsed?

T. They are; and their eclipses are of considerable importance to astronomers, in ascertaining with accuracy the longitude of different places on the earth.

C. I should so much like to know how this is managed.

T. You have heard of chronometers: they are large watches or time-pieces, which go with the greatest possible regularity. They rarely or never keep true time, but they have what is called a *rate*, and this rate in a good chronometer is extremely regular: if, for instance, it gains a tenth of a second in a day, it will gain the same *every day*, and not gain one day more and another day less.

C. But what has this to do with the eclipses of Jupiter's satellites?

T. You have seen the ball at Greenwich fall at one o'clock. The ships' captains in the Thames are watching it, and they compare with it their chronometers the last thing before sailing; and having been previously acquainted with the *rate*, they thus take with them from home true Greenwich time. They also take with them the Nautical Almanac, or White's Ephemeris. At p. 36 and 37 of the latter, they find a table of the eclipses that are visible at various times throughout the year. Sixty eclipses are given for 1853, and they are expressed in Greenwich mean time. We will take the instance given in illustration at p. 37 of the almanac.

"EXAMPLE.—Suppose on the 28th day of June of this year, the time of the emersion of Jupiter's first satellite be observed by a telescope in an unknown meridian to happen at 9h. 54m. 35s. in the morning, mean time at the place. We find by the table that this emersion will take place at the British observatory at 9h. 30m. 59s. the same day: the difference in the times is 23m. 36's., which, being converted into degrees and minutes, will make 5° 54′ [at the rate of 4 minutes to a degree], the longitude of the place of observation, to the *east*, because the

time is *more* than, or in *advance of*, that at the British observatory."

C. I quite understand, and I now see the extreme use of good chronometers; for if 4 minutes are a degree, 1 minute is 15 miles on the equator, or the 4th of a degree, and 1 second is a quarter of a mile, or 4 seconds a mile; so that if a chronometer were a few seconds out, the ship might mistake her course and fall on a rock.

T. By means of the eclipses of Jupiter's satellites, a method has been also obtained of demonstrating that the motion of light is *progressive*, and not *instantaneous*, as was once supposed. Hence it is found, that the velocity of light is nearly 11,000 times greater than the velocity of the earth in its orbit, and more than a million of times greater than that of a ball issuing from a cannon. Rays of light come from the sun to the earth in 8 minutes, that is, at the rate of about twelve millions of miles in a minute.

J. Who discovered these satellites?

T. They were first seen by Galileo in 1610. He took them for telescopic stars, but farther observations convinced him and others that they were planetary bodies.

The relative situation of these small bodies changes at every instant. They are sometimes seen to pass over the face of the planet, and project a shadow in the form of a black spot, which describes a line across it. Jupiter presents also some dark belts on his surface.

CONVERSATION XXII.

Of Saturn.

T. We are now arrived at Saturn in our descriptions, which, till within these seventy years, was esteemed the most remote planet of the solar system.

C. How is he distinguished in the heavens?

T. He shines with a pale dead light, very unlike the brilliant Jupiter, yet his magnitude seems to vie with that of Jupiter himself. The diameter of Saturn is nearly 80 thousand miles: his distance from the sun is more than 900 millions of miles, and he performs his journey round that luminary in a little less than 30 of our years, consequently he must travel at a rate not much short of 21,000 miles an hour.

J. His great distance from the sun must render an abode on Saturn extremely cold and dark too, in comparison of what we experience here.

T. His distance from the sun being between 9 and 10 times

greater than that of the earth, he enjoys about 90 times less light and heat; it has nevertheless been calculated, that the light of the sun at Saturn is 500 times greater than that which we enjoy from our *full moon*.

C. The daylight at Saturn, then, cannot be very contemptible; I should hardly have thought, that the light of the sun even *here* was 500 times greater than that experienced from a full moon.

T. So much greater is our meridian light than this, that during the sun's absence behind a cloud, when the light is much less strong than when we behold him in all his glorious splendour, it is reckoned that our daylight is 90,000 times greater than the light of the moon at its full.

J. But Saturn has several moons, I believe?

T. He is attended by *eight* satellites, or moons, whose periodical times differ very much; the one nearest to him performs a revolution round the primary planet in 22 h. 37 m. 22·6 s.; and that which is most remote takes 79 days and 7 hours for his monthly journey. This last satellite is known to turn on its axis, and in its rotation is subject to the same law which our moon obeys, that is, it revolves on its axis in the same time in which it revolves about the planet.

Prof. Bond of Cambridge, U. S., observed an eighth satellite of Saturn on Sept. 16. 1848; and on Sept. 18th of the same year it was discovered by Mr. Lassell, who named it *Hyperion*. The names of the other seven in their order of distance are *Mimas*, *Enceladus*, *Tethys*, *Dione*, *Rhea*, *Titan*, and *Japetus*. Its revolution is performed in 21 days $4\frac{3}{4}$ hours. Its place is between *Titan* and *Japetus*. Its discovery is somewhat analogous to that of the Asteroids; as there was a large blank between these two moons analogous to the unusual distance between Mars and Jupiter, where the Asteroids were discovered, and where of late a complete cluster of new planets have also been found.

Besides the eight moons, Saturn is encompassed with broad rings, which are probably of considerable importance in reflecting the light of the sun to that planet: the breadth of the inner ring is 20,000 miles, that of the outer ring is 7200 miles, and the vacant space between the two rings is 2839 miles. These rings give Saturn a very different appearance from any of the other planets.

In Nov. 1850, Prof. Bond in America, and Prof. Lassell in England, noticed the appearance of a third and inner ring, which appeared to the latter like as if a veil of crape covered the sky within the ancient inner ring, extending towards the

planet, but leaving the black view of the sky between itself and the body of the planet. There appeared, also, a dark line toward the outer edge of the outer ring. The following is from a sketch made by Mr. Dawes of Wateringburg, at whose observatory the phenomena were seen. It is from the Proceedings of the Astronomical Society for Dec. 13. 1850; and gives a telescopic view of this planet, according to the most recent discoveries.

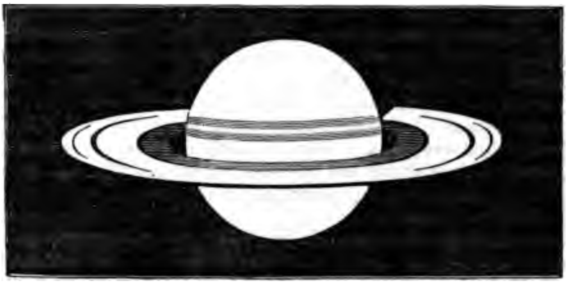


Fig. 21.

J. Is it known of what nature the ring is?

T. Dr. Herschel thinks it no less solid than the body of the planet itself, and he has found that it casts a strong shadow upon the planet. The light of the ring is brighter than that of the planet; for the ring appears sufficiently bright for observation at times when the telescope scarcely affords light enough to give a fair view of Saturn.

C. Is it known whether Saturn turns on its axis?

T. According to Dr. Herschel it has a rotation about its axis in 12 hours 13¼ minutes: this he computed from the equatorial diameter in the proportion of 11 to 10. Dr. Herschel has also discovered, that the ring just mentioned revolves about the planet in 12¼ hours, which is also the time of the planet's rotation on its axis.

CONVERSATION XXIII.

Of Herschel.

T. We have but one other planet to describe, that is Herschel.

J. Was it discovered by Dr. Herschel?

T. It was, on the 13th March, 1781; and therefore by many astronomers it was denominated Herschel; though, by the doctor himself it was named the Georgium Sidus, or Georgian Star, in honour of George III., who was for many years a liberal patron to this great and most indefatigable astronomer. Foreign astronomers usually call this planet *Urănus.*

C. I do not think that I have ever seen this planet.

T. Its apparent diameter is too small to be discerned readily by the naked eye; but it may be easily discovered in a clear night, when it is above the horizon, by means of a good telescope, its situation being previously known from the "Ephemeris."

J. Is it owing to the smallness of this planet, or to its great distance from the sun, that we cannot see it with the naked eye?

T. Both these causes are combined: in comparison of Jupiter and Saturn he is small, his diameter being less than 35 thousand miles; and his distance from the sun is estimated at more than 1800 millions of miles. He performs his journey in 84 of our years; consequently he must travel at the rate of 16,000 miles an hour.

C. But if this planet has been discovered only 60 years, how is it known that it will complete its revolution in 84 years?

T. By a long series of observations it has been found to move with such a velocity as would carry it round the heavens in that period. And all the computations of its places, conducted upon that supposition, are found to be correct.

J. How many moons has Herschel?

T. Sir W. Herschel considers that he has seen *six;* but four alone have been seen with certainty by recent observers:

		d.	h.
Ariel, whose period is		2	12
Umbriel	"	4	4
Oberon	"	8	17
Titania	"	13	11

C. Is there any idea formed as to the light and heat enjoyed by this planet?

T. His distance from the sun is 19 times greater than that of the earth; consequently, since the square of 19 is 361, the light and heat experienced by the inhabitants of that planet must be 361 times less than *we* derive from the rays of the sun. The proportion of light enjoyed by Herschel has been estimated at about equal to the effect of 249 of our full moons.

The following list will give you a general idea of the relative distances of the planets from the sun, with their diameters, and the lengths of their years.

	Relative mean Distance from the Sun.	Diameter.	Length of Year.
		Miles.	Days.
Mercury - -	0·3871	3,200	88
Venus - - -	0·7233	7,700	224¾
Earth - - -	1·0000	7,921	365¼
Mars - - -	1·5237	4,189	687
Jupiter - - -	5·2028	90,000	4,433
Saturn - - -	9·5388	80,000	10,759
Urănus - - -	19·1824	35,000	40,690
Neptune - - -	30·3500	(not determined.)	61,070

The distances are expressed in relation to the earth's distance, reckoned as one. I will explain this at the end of the next chapter. I have not ventured to give any approximate to the diameter of Neptune: it is between that of Saturn and Urănus; but its precise value is not yet ascertained. You will notice that the relative distance between Mars and Jupiter is great, and that there is a great difference between the lengths of their years. In our next conversation, I will give you a table of the new planets, which you will find fall into this interval.

CONVERSATION XXIV.

The New Planet Neptune.—The Nineteen New Asteroids.

J. I shall be glad to have some information respecting the new planets, of which I am aware that many have been lately discovered.

T. The discovery of a planet was wont to give a lasting name to the astronomers who were so fortunate as to have first seen one; and, with the exception of Urănus and of the four asteroids, none other had been discovered until very recently. A new era commenced in 1845; when, on Dec. 8., a new planet was discovered by Dr. Hencke. Like the asteroids, it was between the orbits of Mars and Jupiter; and this has been followed by quite a cluster of others having been detected in the same region of the solar system. But, before I give you the list, I will describe the second in the series of discoveries, which followed in Sept. 1846. It is remarkable as one of the finest illustrations of inductive reasoning and of the perfection of mathematical calculations.

C. I thought the discovery of planets was by mere observation. I cannot understand how the existence of a new planet can be calculated upon; and even if so, how it could be imagined where to look for it?

T. Astronomers had been for a long time puzzled at certain irregularities that occurred with Urănus, which could not be reconciled with any known causes. Much correspondence had taken place upon this matter; and it had occurred to more than one astronomer that these irregularities could only be accounted for on the supposition of there being some unknown planet, with an orbit exterior to that of Urănus. Mr. Adams of Cambridge on the one hand, and M. Le Verrier of Paris on the other hand, had taken up the subject, and had each gone through a course of elaborate mathematical calculations, which led them to give instructions, which were followed, on the one hand, by Professor Challis, and, on the other, by Dr. Gallé and by others, to search certain parts of the heavens in the reasonable hope of detecting the long-suspected stranger.

On July 30th, on August 4th, and on August 12th, 1846, Professor Challis was searching the heavens for this planet, and actually saw it on the two latter days; but, unfortunately, he did not fully compare the respective lists of observations until *after* it had been actually seen by the continental astronomers. Had he done so, he would have then found, as he ultimately did on further reference, that one star was missing in his observations of July 30th, that was found in those of August 12th; and this was the planet Neptune.

C. Dear me, how unfortunate! And what is the history of the actual discovery, or first sight?

T. M. Le Verrier had communicated a second of two papers, on the place of this planet, to the French Academy on the 31st

of August of the same year. The astronomer royal, Mr. Airy, says, in respect to this, "I cannot attempt to convey to you the impression which was made on me by the author's undoubting confidence in the general truth of his theory; by the calmness and clearness with which he limited the field of observation; and by the firmness with which he proclaimed to observing astronomers, '*Look in the place which I have indicated, and you will see the planet well.*'"

On September 23rd he communicated his principal conclusions to the astronomers of the Berlin observatory; and, following his instructions, they examined the regions of the heavens indicated to them; and on the self-same evening, Dr. Gallé was the first to obtain a sight of the new planet, whose place had thus been so faithfully indicated.

On September 29th, Professor Challis, who had been no less struck with the sagacity and clearness of M. Le Verrier's latest indications, which only that day reached him, made observations, and examined some 300 stars, of which one caught his attention, and was specially noted, as it "seemed to have a disc;" and this subsequently proved to be Neptune. The following night was unfavourable; and on October 1st, the information reached him of its having been, as I before said, recognised by Dr. Gallé on the 23rd of September.

Another curious thing in the history of this planet is, that it was actually seen on May 8th and 10th, 1795, by Lalande; but its subsequent absence, as it moved in its orbit, was overlooked. It was also seen by Dr. Lamont at Munich, on October 25th, 1845, and on September 7th, 1846; but was taken then to be a star, and noted as such.

It has a ring; and is very like Saturn in appearance. Lassell has discovered one satellite, which revolves in 5 days 21 hours. Whether this is the only one, remains for future observation. He once thought he caught sight of a second; but this has not been confirmed. Neptune's year, or period of revolution in the orbit, is 61,070 days. Its diameter is not known, but probably between that of Jupiter and Saturn.

C. And what are the other new planets?

T. The following is a complete list of the planets very recently discovered between the orbits of Mars and Jupiter, and among which I have placed the four asteroids.

	Relative Mean Distance from the Sun.	Length of Year.	Discovered by	Time of Discovery.	Symbol.
		Days.			
8. Flora	2·202	1193	Hind.	Oct. 18. 1847.	
18. Melpomene	2·297	1275	Hind.	June 24. 1852.	
12. Victoria	2·335	1303	Hind.	Sept. 13. 1850.	
20. Massilia	2·350	1316	Chacornac.	Sept. 20. 1852.	
4. *Vesta*	2·361	1326	*Olbers.*	*Mar.* 29. 1807.	
7. Iris	2·381	1342	Hind.	Aug. 13. 1847.	
9. Metis	2·386	1346	Graham.	Apr. 25. 1848.	
6. Hebe	2·426	1380	Hencke.	July 1. 1847.	
11. Parthenope	2·426	1380	De Gasparis.	May 11. 1850.	
19. Fortuna	2·446	1397	Hind.	Aug. 22. 1852.	
17. Thetis	2·491	1436	Luther.	Apr. 17. 1852.	
5. Astræa	2·577	1513	Hencke.	Dec. 8. 1845.	
13. Egeria	2·579	1513	De Gasparis.	Nov. 2. 1850.	
14. Irene	2·584	1517	Hind.*	May 19. 1851.	
21. Lutetia	2·605	1536	Goldschmidt.	Nov. 15. 1852.	
15. Eunomia	2·648	1573	De Gasparis.	July 29. 1851.	
3. *Juno*	2·671	1593	*Harding.*	*Sept.* 1. 1804.	
23. Thalia	2·707	1627	Hind.	Dec. 15. 1852.	
1. *Ceres*	2·768	1682	*Piazzi.*	*Jan.* 1. 1801.	
2. *Pallas*	2·773	1686	*Olbers.*	*Mar.* 28. 1802.	
22. Calliope	2·941	1842	Hind.	Nov. 16. 1852.	
16. Psyche	3·101	1995	De Gasparis.	Mar. 17. 1852.	
10. Hygeia	3·122	2015	De Gasparis.	Apr. 12. 1849.	

I have placed them in the order of their distance from the sun; and have included the four asteroids, that were discovered early in the present century, inasmuch as they belong to this group. Exclusive of these four, there are no less than nineteen, three of which were discovered while I was preparing the list.

C. I see then that Chacornac, Graham, Luther and Goldschmidt have each discovered *one*; Hencke, *two*; De Gasparis, *five*, and, in a certain sense, six; and Hind no less than *eight*.

T. Yes; then add to this, Le Verrier's discovery of Neptune;

* Discovered, independently, by De Gasparis, May 23. 1851.

and the *one* each discovered by Harding and Piazzi, and the *two* by Olbers. In respect to the symbols, which I have placed at the right hand, several yet remain to be selected; and the others are not uniformly accepted by astronomers. Many are in the habit of referring to them by placing in a small circle the number representing the order of their discovery. I have placed the number at the left hand of the name of each planet; and you will find, if you compare at your leisure these figures with the dates of the discovery, that they follow in regular order. 1, 2, 3, and 4 belong to the early group of asteroids; 5 to Astræa, the first of the recent ones. Neptune does not require the 6 to distinguish him, he not being of this group.

J. I don't quite comprehend how the second column expresses the distance from the sun.

T. This requires a little explanation. It is there expressed in *distances of the earth*, and is given in whole numbers and decimals. For instance, the earth is 95 millions of miles from the sun; Flora is somewhat more than twice as far off: the exact relation is expressed by 2·202; and the actual distance is obtained by multiplying those figures by 95, and putting the dot in the same place, counting from the right thus: —

$$\begin{array}{r} 2{\cdot}202 \\ 95 \\ \hline 11010 \\ 19818 \\ \hline 209{\cdot}190; \end{array}$$

which shows that Flora is somewhat more than 209 millions of miles from the sun; in fact, about 209,190,000 miles off.

I will not trouble you with anything further respecting these bodies now. You will find the *place* of their discovery duly mapped out successively year by year in the *Illustrated London Almanack*. I have no information for you respecting the relative diameter of these bodies; for they are not measurable.

CONVERSATION XXV.

Of Comets.

T. Besides the seven primary planets, and the eighteen secondary ones, or satellites, which we have been describing, there are other bodies belonging to the solar system, called comets.

C. Do comets resemble the planets in any respect?

T. Like them, they are supposed to revolve about the sun in elliptical orbits, and to describe equal areas in equal times; but they do not appear to be adapted for the habitation of animated beings, owing to the great degrees of heat and cold to which, in their course, they must be subjected, in consequence of the great eccentricity of most of their orbits.

The comet seen by Sir Isaac Newton in the year 1680 was observed to approach so near the sun, that its heat was estimated by that great man to be 2000 times greater than that of red-hot iron.

J. It must have been a very solid body to have endured such a heat without being entirely dissipated.

T. So indeed it should seem; and a body thus heated must retain its heat a long time; for a red-hot globe of iron, of a single inch in diameter, exposed to the open air, will scarcely lose all its heat in an hour; and it is said, that a globe of red-hot iron, as large as our earth, would scarcely cool in 50,000 years.

C. Are there many comets?

T. No less than 607 have been authenticated since the commencement of the Christian era; and, since many of those seen during the last two centuries are telescopic comets, it is inferred by Mr. Hind, in his book "On Comets," which you would do well to consult, that, since many such were inevitably not seen during the earlier centuries, there must be upwards of 4000 of these erratic bodies.

C. Are the periodical times of all the comets known?

T. No; the periods of only a few are known with any degree of accuracy: for instance, *Halley's Comet.* A comet had been seen in A.D. 1531 and in A.D. 1607; Halley determined the orbits of these comets, and also of another that was visible in 1682, and was so struck with their similarity that he concluded they were one and the same; and accordingly it was again looked for, and made its appearance in 1759. Its arrivals at its perihelion, or nearest distance from the sun, were at intervals, respectively, of 76·14, 74·88, and 76·49 years. Its next period occurred, within our own time, in 1835, and was performed in 76·68 years. These differences in the intervals depend on the disturbing causes to which it is exposed.

On looking back to the history of comets, astronomers recognise this comet as having been seen in many of its periodical returns; and are tolerably satisfied that it is the same which was seen over the city of Rome in the year 11, and shortly before Agrippa's death. Mr. Hind gives the times of 24 periods, of which seven of the early appearances are tolerably sure.

Encke's Comet.—The period of this comet is about 3¼ years. It was last seen at its perihelion on March 14th, 1852. At each return, it arrives 2½ hours sooner than the estimated time, so that its period is gradually decreasing, which Encke has supposed to be due to etherial medium in space opposing a resistance to its motion; and it is suggested whether or not it may not ultimately fall into the sun; but ages may elapse before this could happen.

Biela's Comet has a period of a little more than 6⅔ years. It was last seen at the end of August, 1852. On its previous appearance in 1846, and some weeks after it had been recognised, it was found to have separated into two parts, which continued in the same general path, but varied in their relative distance, averaging 155,000 miles. On its reappearance in 1852, the second comet was thought to have been seen in its company; and, if so, was 1¼ millions of miles from it.

This is the comet that excited so much alarm in 1832; for it had been calculated to cross the orbit of the earth about a month before the earth itself arrived at that part; and the public argued that if, by any unsuspected cause, it were retarded in its course, a collision might occur.

C. If this had occurred, our planet would have been destroyed. And, as we had so narrow an escape that time, I suppose we run some little risk in future.

T. There is not much cause for alarm, either in respect to this or to any other comet, if we may believe M. Arago, who says the chances in our favour are two hundred and fifty millions to one.

C. What are the respective distances of those comets from the sun?

T. I must explain to you that we see comets when they are at or near their perihelion, or nearest distance from the sun; and they are invisible to us, when they go far away into space to their aphelion, or farthest distance: the words mean *near* the *sun*, and *from* the sun. The following are the distances in miles:

	Perihelion dist.	Aphelion dist.
Halley's	55,900,000	3,370,300,000
Encke's	32,120,000	223,840,000
Biela's	81,600,000	590,100,000.

J. Do all bodies move faster or slower in proportion as they are nearer to, or more distant from, their centre of motion?

T. They do: for if you meditate upon the last six or seven lectures, you will recollect that of Herschel, which is the most remote planet in the solar system, travels at the rate of 16,000

miles an hour; Saturn, the next nearer in the order, 21,000 miles; Jupiter, 28,000 miles; Mars, 53,000 miles; the Earth, 65,000 miles; Venus, 75,000 miles; and Mercury at the rate of 105,000 miles in an hour. But a comet has a progressive motion, in that part of its orbit which is nearest the sun, of many times the velocity of Mercury.

C. Were not comets formerly dreaded as awful prodigies, intended to alarm the world?

T. Comets are frequently accompanied with a luminous train, called the tail, issuing from the body in a line opposite to the sun, but which, to uninformed people, has been a source of terror and dismay.

J. Do comets shine by their own light?

T. The general opinion is that they shine, like the planets, by reflected light; and although some appearances in regard to the relative increase of brilliancy are not always in direct proportion to their nearness to the sun, these anomalies are reasonably to be traced to physical changes in the several parts of which the comet is composed.

C. What are those parts?

T. They are the *nucleus*; the *head*, or *coma*; and the *tail*.

The *nucleus* is a small, brilliant, and diamond-like substance in the centre: it has been measured in some comets. In Biela's it is given at from 70 to 112 miles; in other comets two, three, four, and five thousand miles. In the comet of 1845, the nucleus was as large as the earth. Halley's comet, at one time, showed a nucleus from 250 to 1000 miles in diameter; and in a few months it appeared to be 97,000 miles.

The *head* includes the bright surrounding light and the nebulous coma, or atmosphere, about the nucleus. The head of the comet of 1811 was about a million of miles in diameter; that of Halley's and of Encke's upwards of a third of a million of miles; but the diameters much vary as they approach the sun, becoming less and not greater.

The *tail* is the most brilliant appendage of comets, but is not found with all. Its visible length is extremely various; in some extending over a few degrees of the heavens, and in others, as in the "EXPECTED GREAT COMET," upwards of 10°. Some tails are bifurcated, others are bushy and branchy; some are long and slender, others short and thick. The actual lengths of the tails vary from about a quarter of a million to 100 and 200 millions of miles.

E. When is the great comet expected? I hope we may see it. Do tell us something about it.

T. It was seen last in A. D. 1556; its period is not exactly

known; but is computed by M. Bommé, from the elements respectively of Halley and of Hind, to be somewhat over 300 years, and is to be looked for in August 1858 or August 1860. It is supposed to have been the same as that seen in 1264, and will be a most magnificent visitor. When its head was in the horizon, its tail extended beyond the zenith. It is the greatest of all the comets, and excited universal wonder.

E. Of what does the tail of a comet consist?

T. That, my dear, it is impossible to determine: all I could say would be only conjecture. After all the exertions of astronomers of all countries, there is no class of celestial objects whose theory is so little advanced as that of comets. We will, therefore, dwell no longer upon it.*

CONVERSATION XXVI.

Of the Sun.

T. Having given you a particular description of the planets which revolve about the sun, and also of the satellites which travel round the primary planets as central bodies, while they are carried at the same time with these bodies round the sun, we shall conclude our account of the solar system by taking some notice of the Sun himself.

J. You told us, a few days ago, that the sun has a rotation on its axis; how is that known?

T. By the spots on his surface it is known that he completes a revolution from west to east on his axis in about 25 days, two days less than his *apparent* revolution, in consequence of the earth's motion in her orbit in the same direction.

C. Is the figure of the sun globular?

T. No; the motion about its axis renders it spheroidal, having its diameter at the equator longer than that which passes through the poles.

The sun's diameter is more than equal to 100 diameters of the earth, and therefore his bulk must be more than a million of times greater than that of the earth; but the density of the matter of which it is composed is four times less than the density of our globe.

We have already seen that, by the attraction of the sun, the planets are retained in their orbits, and that to him they are indebted for light, heat, and motion.

* Those who wish for more particulars on this subject are referred to "Scientific Notices of Comets, from the French of M. Arago, by Col. C. Gold;" and Mr. Hind's work, already mentioned.

We can hardly suppose, however, that the sun, a body three hundred times larger than all the planets together, was created only to preserve the periodic motions, and give light and heat to the planets. Many astronomers have conjectured that its atmosphere only is luminous, while its body is opaque, and probably of a constitution analogous to that of the planets. Allowing, therefore, that its luminous atmosphere only extricates heat, we see no reason why the sun itself should not be inhabited.

J. For my part, sir, I am at once inclined to believe this; because it accords completely with all one's preconceived sentiments of the wisdom and goodness of the Great Creator of the universe.

T. Mr. Dawes has modified the eye-piece of his telescopes, so as to have enabled him to examine more closely the spots on the surface of the sun. Fig. 22. represents a spot examined on Jan. 17. and Jan. 23. 1852. It consists of a *penumbral* portion *a*, of the *cloudy stratum*, *b*, which had not previously been noticed;

Jan. 17. Jan. 23.

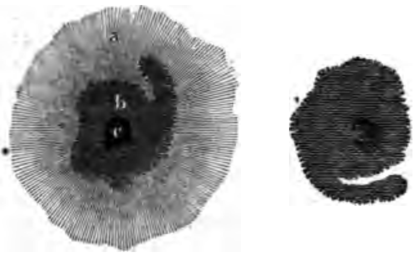


Fig. 22.

and of the dark *nucleus*, *c*. The cloudy stratum *b*, seems to be much below the penumbra, and does not appear as self-luminous, but rather to absorb light. It is sometimes mottled with patches more luminous than the rest of it, but not so luminous as the penumbra *a*. The black nucleus is supposed to be the body of the sun itself. The two figures show a remarkable instance of an *actual rotatory* motion of the cloudy stratum around the nucleus from Jan 17. to Jan. 23.

The *quantity* of spots on the sun varies year by year; for five years they increase in number to a *maximum;* and in five following years decrease to a *minimum*.

CONVERSATION XXVII.

Of the Fixed Stars.

T. We will now put an end to our Astronomical Conversations, by referring again to the fixed stars, which, like our sun, shine by their own light.

C. Is it then certain that the fixed stars are of themselves luminous bodies, and that the planets borrow their light from the sun?

T. By the help of telescopes it is known that Mercury, Venus, and Mars shine by a borrowed light, for, like the moon, they are observed to have different phases, according as they are differently situated with regard to the sun. The immense distances of Jupiter, Saturn, and Herschel do not allow the difference between the perfect and imperfect illumination of their discs or phases to be perceptible.

Now the distance of the fixed stars from the earth is so great that reflected light would be much too weak ever to reach the eye of an observer here.

J. Is this distance ascertained with any degree of precision?

T. It is not; but it is known with certainty to be so great, that the whole diameter of the earth's orbit — viz. 190 millions of miles, is but a point in comparison of it; and hence it is inferred that the distance of the nearest fixed star cannot be less than a hundred thousand times the length of the earth's orbit; that is a hundred thousand times 190 millions of miles, or, 19,000,000,000,000 miles; this distance being immensely great, the best method of forming some clear conception of it is to compare it with the velocity of some moving body, by which it may be measured. The swiftest motion with which we are acquainted is that of light; which, as we have seen, is at the rate of 12 millions of miles in a minute; and yet light would be about three years in passing from the nearest fixed star to the earth.

A cannon-ball, which may be made to move at the rate of 20 miles in a minute, would be 1800 thousand years in traversing the distance. Sound, the velocity of which is 13 miles in a minute, would be more than 2700 thousand years in passing from the star to the earth. So that, if it were possible for the inhabitants of the earth to see the light, to hear the sound, and to receive the ball of a cannon discharged at the nearest fixed star, they would not perceive the light of its explosion for three years after it had been fired; nor receive the ball till 1800 thousand years had elapsed; nor hear the report for 2700 thousand years after the explosion.

C. Are the fixed stars at different distances from the earth?

T. Their magnitudes, as you know, appear to be different from one another, which difference may arise either from a diversity in their real magnitude, or in their distances, or from both these causes acting conjointly. It is the opinion of Dr. Herschel, that the different apparent magnitudes of the stars arise from the different distances at which they are situated; and therefore he concludes, that stars of the seventh magnitude are at seven times the distance from us that those of the first magnitude are.

By the assistance of his telescopes he was able to discover stars at 497 times the distance of *Sirius* the Dog-star: from which he inferred, that with more powerful instruments we should be able to discover stars at still greater distances.

J. I recollect you told us once, that it had been supposed by some astronomers, that there might be fixed stars at so great a distance from us, that the rays of their light had not yet reached the earth, though they had been travelling at the rate of 12 millions of miles in a minute, from the first creation up to the present time.

T. I did; it was one of the sublime speculations of the celebrated Huygens. Dr. Halley has also advanced what, he says, seems to be a metaphysical paradox,—viz. that the number of fixed stars must be more than finite, and some of them at a greater than a finite distance from others: and Mr. Addison has observed, that this thought is far from being extravagant, when we consider, that the universe is the work of infinite power, promoted by infinite goodness, and having an infinite space to exert itself in: so that our imagination can set no bounds to it.

C. What can be the use of these fixed stars?—not to enlighten the earth: for a single additional moon would give us much more light than them all, especially if it were so contrived as to afford us its assistance at those intervals when our present moon is below the horizon.

T. You are right; they could not have been created for our use; since thousands, and even millions, are never seen but by the assistance of glasses, to which but few of our race have access. Your minds indeed are too enlightened to imagine, like children unaccustomed to reflection, that all things were created for the enjoyment of man. The earth on which we live is but one of many primary planets circulating perpetually round the sun as a centre, and with these are connected secondary planets or moons, all of which are probably teeming with living beings, capable, though in different ways, of enjoying the bounties of the great First Cause.

The fixed stars then are probably suns, which, like our sun,

serve to enlighten, warm, and sustain other systems of planets and their dependent satellites: and each, like our sun, may be the residence of animals rational and irrational.

J. Would our sun appear as a fixed star at any great distance?

T. It certainly would: and Dr. Herschel thinks there is no doubt, but that it is one of the heavenly bodies belonging to that tract of the heavens known by the name of the *Milky Way.*

C. I know the milky way in the heavens, but I little thought that I had any concern with it otherwise than as an observer.

T. The milky way consists of fixed stars, too small to be discerned with the naked eye; and, if our sun be one of them, the earth and other planets are closely connected with this part of the heavens.

HYDROSTATICS.

CONVERSATION I.

INTRODUCTION.

Father—Charles—Emma.

F. We shall now proceed with the branch of science called *Hydrostatics.*

E. That is a difficult word: what are we to understand by it?

F. Almost all the technical terms made use of in science are either Greek or derived from the Greek language. The word *hydrostatics* is formed of two Greek words which signify *water*, and the science which considers the *weight of bodies*. But hydrostatics, as a branch of natural philosophy, treats of the nature, gravity, pressure, and motion of fluids in general; and of the methods of weighing solids in them. I ought to tell you that many writers divide this subject into two distinct parts,—viz. *hydrostatics* and *hydraulics;* the latter relates particularly to the motion of water through pipes, conduits, &c.

In these Conversations I shall pay no regard to this distinction, but shall, under the general title of hydrostatics, describe the properties of all fluids, but principally those of water; explaining, as we go on, the motions of it, whether in pipes, pumps, siphons, engines of different kinds, fountains, &c. Do you know what a fluid is?

C. I know how to distinguish a fluid from a solid: water and wine are fluids, but why so called I cannot tell.

F. A fluid is generally defined as a body, the parts of which readily yield to any impression, and in yielding are easily moved among each other.

E. But this definition does not notice the wetting of other bodies brought into contact with a fluid. If I put my fingers into water or milk, a part of it adheres to them, and they are said to be wet.

F. Every accurate definition must mark the qualities of all the individual things defined by it: now there are many fluids which have not the property of wetting the hand when plunged into them. The air we breathe is a fluid, the parts of which

yield to the least pressure, but it does not adhere to the bodies surrounded by it, like water.

E. Air, however, is so different from water, that in this respect, they will scarcely admit of comparison.

C. I have sometimes dipped my finger into a cup of quicksilver, but none of the fluid came away with it.

F. You are right; and hence you will find that some writers on natural philosophy distinguish between fluids and liquids. Air, quicksilver, and melted metals, are fluids, but not liquids; while water, milk, beer, wine, oil, spirits, &c. are fluids and liquids.

C. Are we then to understand, that liquids are known by the property of adhering to different substances which are immersed in them?

F. This description will not always hold; for though mercury will not stick to your hand, if plunged into a cup of it, yet it will adhere to many metals, as tin, gold, &c. The distinction between liquids and fluids is introduced into books more on account of common convenience, than philosophical accuracy; the liquid is distinguished by the cohesion of its particles with each other.*

E. You said, I believe, that a fluid is defined as a body, whose parts yield to the smallest force impressed?

F. This is the definition of a perfect fluid: and the less force that is required to move the parts of a fluid, the more perfect is that fluid.

C. But how do people reason respecting the particles of which fluids are composed? have they ever seen them?

F. Philosophers imagine they must be exceedingly small, because, with their best glasses, they have never been able to discern them. And they contend, that these particles must be round and smooth, since they are so easily moved among and over one another. If they are round, you know, there must be vacant spaces left between them.

E. How is this?

F. Suppose a number of cannon-balls were placed in a large tub, or any other vessel, so as to fill it up even with the edge; though the vessel would contain no more large balls, it would hold, in the vacant spaces, many smaller shot; and between these, others still smaller might be introduced; and when the vessel would contain no more shot, a quantity of sand might be shaken in, and between the pores of these, water or other fluids would readily insinuate themselves.


Fig. 1.

* See page 4.

E. This I understand; but are there any other proofs that water is made up of such globular particles?

F. There are several: all aquatic plants, that is, plants which live in water, have their pores round, and are thereby adapted to receive the same shaped particles of water; all mineral and medicinal waters evidently derive their peculiar character from the different substances taken into their pores; from which it has been concluded that the particles of water are globular, because such admit of the largest intervals.

Upon this principle, tinctures, as those of bark, rhubarb, &c. are made; a quantity of the powder of bark, or any other substance, is put into spirits of wine; the very fine particles are taken into the pores of the spirit; these change the colour of the mass, though it remains as transparent as it was before.

C. But in these cases is not the bulk of the fluid increased?

F. In some instances it is; but in others it will remain the same, as the following very easy experiment will show:

Take a phial with some rain water, mark very accurately the height at which the water stands, after which introduce a small quantity of salt, which, when completely dissolved, you will find has not in the least increased the bulk of the water. When the salt is taken up, sugar may be dissolved in the water, without making any addition to its bulk.

E. Are we then to infer, that the particles of salt are smaller than those of water, and lie between them, as the small shots lie between the cannon-balls; and that the particles of sugar are finer than those of salt, and, like the sand among the shot, will insinuate themselves into vacuities, too small for the admission of the salt?

F. I think the experiment fairly leads to that conclusion. Another fact respecting the particles of fluids deserving your notice is, that they are exceedingly hard, and almost incapable of compression.

C. What do you mean, sir, by compression?

F. I mean the act of squeezing anything, in order to bring its parts nearer together. Almost all substances with which we are acquainted may, by means of pressure, be reduced into a less space than they naturally occupy. But water, oil, spirits, quicksilver, &c. cannot by any pressure of which human art or power is capable, be reduced into a space *sensibly* less than they naturally possess.

E. Has the trial ever been made?

F. Yes, by some of the ablest philosophers that ever lived. And it has been found, that water will find its way through the

pores of gold even, rather than suffer itself to be compressed into a smaller space.

C. How was the experiment made?

F. At Florence, a celebrated city in Italy, a globe made of gold was filled with water, and closed so accurately that none of it could escape. The globe was then put into a press, and a little flattened at the sides; the consequence of which was, that the water came through the fine pores of the golden globe, and stood upon its surface like drops of dew.

C. Would not the globe contain as much after its sides were bent in as it did before?

F. It would not; and as the water forced its way through the gold rather than suffer itself to be brought into a smaller space, than it naturally occupied, it was concluded, at that time, that water was incompressible. Later experiments have, however, shown that those fluids which were esteemed incompressible are, in a very small degree, as, perhaps, one part in twenty thousand, capable of compression.

E. Is it on this account you conclude that the particles are very hard?

F. Undoubtedly: for if they were not so, you can easily conceive that since there are vacuities between them, as we have represented in the preceding figure, they must, by very great pressure, be brought closer together, and would *evidently* occupy a less space, which is contrary to fact. Fluids, like solids, are elastic; a drop of mercury falling from a height rebounds.

Note.—Water, oil, spirits, &c. are said to be incompressible, not because they are absolutely so, but because their compressibility is so very small, as to make no sensible difference in calculations relative to the several properties of those fluids.

Mr. Canton discovered the compressibility of water in the year 1761, and he says, that from repeated trials he found that water will expand, and rise in a tube, by removing the weight of the atmosphere, about one part in 21·740, and will be as much compressed under the weight of an additional atmosphere.

Mr. Perkins found that a pressure of 1120 atmospheres produced a diminution of $\frac{3}{80}$ in the bulk of water And Professor Oersted found each additional atmospheric pressure compressed water 46 millionths of its bulk.

A fluid that has no immediate tendency to expand when at liberty is commonly considered as a liquid, as water, oil, &c. See Young's Lectures, vol. i. p. 259.

CONVERSATION II.

Of the Weight and Pressure of Fluids.

F. The parts or particles of fluids act, with respect to their weight or pressure, independently of each other.

E. Will you explain what you mean by this?

F. You recollect that, by the attraction of cohesion *, the parts of all solid substances are kept together, and press into one common mass. If I cut a part of this wooden ruler away, the rest will remain in precisely the same situation as it was before. But if I take some water out of the middle of a vessel, the remainder flows instantly into the place from whence that was taken, so as to bring the whole mass to a level.

C. Have the particles of water no attraction for each other?

F. Yes; in a slight degree. The globules of dew † on cabbage-plants prove, that the particles of water have greater attraction for one another than they have for the leaf on which they stand. Nevertheless, this attraction is very small, and you can easily conceive, that if the particles are round they will touch each other in very few parts, and slide with the smallest pressure. Imagine that a few of the little globules were taken out of the vessel exhibited at p. 143, and it is evident that the surrounding ones would fall into their place. It is upon this principle that the surface of every fluid, when at rest, is horizontal or level.

C. Is it upon this principle that water-levels are constructed?

F. It is; the most simple kind of water-level is a long wooden trough filled to a certain height with water; the surface of which shows the level of the place upon which it stands.

C. I did not allude to this kind of level, but to those smaller ones contained in glass tubes.

F. These are, more properly speaking, air-levels. They are thus constructed: D is a glass cylindrical tube fixed into L, a socket made generally of brass. The glass is nearly filled with water, or some other fluid, in which is inclosed a single bubble of air. When this bubble fixes itself at the mark *a*, made exactly in the middle of the tube, the place on which the instrument stands is perfectly level. When it is not level, the bubble will rise to the higher end.

Fig. 2.

E. What is the use of these levels?

F. They are fixed to a variety of philosophical instruments,

* See Mechanics, Conversation III. † See Mechanics, Conversation IV.

such as quadrants, and telescopes for surveying the heavens; and theodolites for taking the level of any part of the earth, or for measuring horizontal angles. They are also useful in the more common occurrences of life. A single instance will show their value: clocks will not keep true time unless they stand very upright; now, by means of one of those levels, you may easily ascertain whether the bracket upon which the clock in the passage stands is level.

E. But I remember when Mr. F——— brought home your clock, he tried if the bracket was even by means of Charles's marbles. How did he know by this?

F. The marble being round, touched the board in a point only, consequently the line of direction* could not fall through that point, unless the bracket was very level; therefore, when the marble was placed in two or more different parts of the board, and did not move to one side or the other, he might safely conclude that it was a level.

C. Then the water level and the rolling of the marble depend on the same principle?

F. They do, upon the supposition that the particles of water are round. The water-level will, however, be the most accurate, because we may imagine that the parts of which water is composed are perfectly round, and therefore, as may be geometrically proved, they will touch only in an infinitely small point; whereas marbles, made by human contrivance, touch in many such points.

We now come to another very curious principle in this branch of science,—viz. *that fluids press equally in all directions.* All bodies, both fluid and solid, press downwards by the force of gravitation, but fluids of all kinds exert a pressure upwards and sideways equal to their pressure downwards.

E. Can you show any experiments in proof of this?

F. A B C is a bended glass tube: with a small glass funnel, pour into the mouth A a quantity of sand. You will find that, when the bottom part is filled, whatever is poured in afterwards will stand in the side of the tube A B, and not rise in the other side B C.

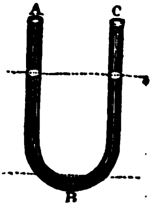


Fig. 3.

C. The reason of this is, that by the attraction of gravitation, all bodies have a tendency to the earth †; that is, in this case, to the lowest part of the tube; but if the sand as-

* See Mechanics, Conversation IX. † See Mechanics, Conversation V.

cended in the side B C, its motion would be directly the reverse of this principle.

F. You mean to say, that the pressure would be upwards, or *from* the centre of the earth.

C. It certainly would.

F. Well, we will pour away the sand, and put water in its place: what do you say to this?

E. The water is level in both sides of the tube.

F. This proves, that with respect to fluids, there is a pressure upwards at the point B as well as downwards. I will show you another experiment.

Fig. 4.

A B is a large jar having a flat bottom: *a b* is a tube open at both ends. While I fill the jar with water, I take care to hold the small tube so close to the bottom of the jar as to prevent any water from getting into the tube. I then raise it a little, and you see it is instantly filled with water from the jar.

C. It is; and the water is level in the jar and the tube.

F. The tube you saw was filled by means of the pressure upwards, contrary to its natural gravity.

Take out the tube; now, the water having escaped, it is filled with air. Stop the upper end *a* with a cork, and plunge it into the jar, the water will rise as high as *b*.

E. What is the reason of this, papa?

F. The air, with which the tube was filled, is a body and occupies space; so that unless the water were first to force it out from the tube, it cannot take its place.

C. If air be a substance, and the tube is filled with it, how can any water at all make its way into the tube?

F. This is a very proper question. Air, though a substance, differs from water in its being easily compressible; that is, the air, which, by the natural pressure of the surrounding atmosphere, fills the tube, may, by the additional upward pressure of the water, be reduced into a smaller space, as *a b*. Another experiment will illustrate the difference between compressible and incompressible fluids.

Fill the tube, which has still a cork in one end, with some coloured liquor, as spirits of wine; over the other end place a piece of pasteboard, held close to the tube to prevent any of the liquor from escaping. In this way introduce the tube into a vessel of water, keeping it perpendicular all the time. You

may now take away the pasteboard, and force the tube to any depth; but the spirit is not like the air; it cannot in this manner be reduced into a space smaller than it originally occupied.

E. Why did not the spirits of wine run out of the tube into the water?

F. Because spirits are lighter than water; and it is a general principle that the lighter fluid always ascends to the top.

Take a thin piece of horn or pasteboard, and while you hold it by the edges, let your brother put a pound weight upon it; what is the result?

E. It is almost bent out of my hand.

F. Introduce it now into a vessel of water at the depth of twelve or fifteen inches, and bring it parallel to the surface. In this position, it sustains many pounds weight of water.

C. Nevertheless, it is not bent in the least.

F. Because the upward pressure against the lower surface of the horn is exactly equal to the pressure downwards, or, which is the same thing, it is equal to the weight of the water which it sustains on the upper surface.

E. Is this the case, be the depth what it may?

F. It is; because, at all depths, the pressures upwards and downwards are always equal: in other words, "fluids press equally in all directions."

You may vary these experiments by yourselves till we meet again, when we will resume the subject.

C. Do I understand that, if I apply a pressure of one pound to a liquid that is confined in a vessel, I distribute a pressure of a pound throughout the surface of the vessel?

F. You do more than this; and hence arise some important consequences: if your power of one pound is applied by pressing down a piston that has, say, a square inch of surface, you distribute a pressure of one pound to every square inch of surface on the containing vessel; and if it presented a square foot or 144 square inches of surface, your one pound would have been increased to 144 pounds in all.

CONVERSATION III.

Of the Weight and Pressure of Fluids.

C. When you were explaining the principle of the Wheel and Axle*, I asked the reason why, as the bucket ascended near the

* See Mechanics, Conversation XVII.

top of the well, the difficulty in raising it increased? I have just now found another part of the subject beyond my comprehension. After the bucket is filled with water, it sinks to the bottom of the well, or as far as the rope will suffer it: but in drawing it up through the water, it seems to have little or no weight till it has ascended to the surface of the water. How is this accounted for?

F. I do not wonder that you have noticed this circumstance as singular. It was long believed by the ancients that water did not gravitate, or had no weight, in water; or as they used to express it more generally, that fluids do not gravitate *in proprio loco*.

E. I do not understand the meaning of these hard words.

F. I will explain their meaning without translating them; because a mere translation would give you a very inadequate idea of what the writers intended to express by them.

No one ever doubted that water and other fluids had weight, when considered by themselves; but it was supposed that they had no weight when immersed in a fluid of the same kind. The fact which your brother has just mentioned respecting the bucket was the grand argument, upon which they advanced and maintained this doctrine.

E. Does it not weigh anything, then, till it is drawn above the surface?

F. You must, my little girl, have patience, and you shall see how it is. Here is a glass bottle A, with a stopcock B, cemented to it, by means of which the air may be exhausted from the bottle, and prevented from returning into it again. The whole is made sufficiently heavy to sink in the vessel of water C D.

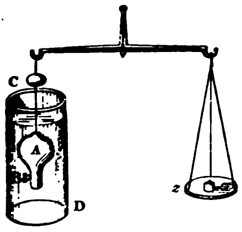


Fig. 5.

The bottle must be weighed in air, that is, in the common method; and suppose it weighs 12 ounces, let it now be put into the situation which is represented by the figure, when the weight of the bottle must be again taken by putting weights into the scale *z*. I then open the stopcock, while it is under water, and the water immediately rushes in and fills the bottle, which overpowers the weights in the scale. I now put other weights, say 8 ounces, into the scale, to restore the equilibrium between the bottle and scale. It is evident, then, that 8 ounces is the weight of the water in the bottle, while weighed under water. Fasten the cock, and weigh the bottle in the usual way in the air.

C. It weighs something more than 20 ounces.

F. That is 12 ounces for the bottle and 8 ounces for the water, besides a small allowance to be made for the drops of water that adhere to the outside of the bottle. Does not this experiment prove that the water in the bottle weighed just as much in the jar of water as it weighed in the air?

E. I think it does.

F. Then we are justified in concluding, that the water in the bucket, which the bottle may represent, weighed as much while under water in the well, as it did after it was raised above the surface.

C. This fact seems decisive, but the difficulty still remains in my mind; for the weight of the bucket is not felt till it is rising above the surface of the water.

F. It may be thus accounted for: any substance of the same specific gravity with water may be plunged into it, and it will remain wherever it is placed, either near the bottom, in the middle, or towards the top, consequently it may be moved in any direction with the application of a very small force.

E. What do you mean by the specific gravity of a body?

F. The *specific gravity* of any body is its weight *compared* with that of any other body.* Hence it is also called the *comparative* gravity: thus if a cubic inch of water be equal in weight to a cubic inch of any particular kind of wood, the specific or comparative gravities of the water and that particular wood are equal. But since a cubic inch of deal is lighter than a cubic inch of water, and water is lighter than the same bulk of lead or brass, we say the specific gravity of lead, or brass, is greater than that of water, and the specific gravity of water is greater than that of deal.

C. The water in the bucket must be of the same specific gravity with that in the well, because it is a part of it.

F. And the wooden bucket differs very little in this respect from the water; because though the wood is lighter, yet the iron of which the hoops and handle are composed is specifically heavier than water; so that the bucket and water are nearly of the same specific gravity with the water in the well; and, therefore, it is moved very easily through it.

Again, we have already proved that the upward pressure of fluids is equal to the pressure downwards; therefore the pressure at the bottom of the bucket upwards being precisely equal to the same force in a contrary direction, the application of a very small force, in addition to the upward pressure, will cause the bucket to ascend.

* See Conversation X., &c.]

E. Do you account for the easy ascent of the bucket upon the same principle by which you have shown that horn or pasteboard will not be bent, when placed horizontally at any depth of water?

F. Yes, I do; and I will show you some other experiments to prove the effect of the upward pressure.

Take a glass tube, open at both ends, the diameter of which is about the eighth of an inch, thrust it into a vessel of water, and close the top with your thumb; you may now take it out of the water, but it will not empty itself, so long as the top is kept closed.

C. This is not the upward pressure of water, because the tube was taken out of it.

F. You are right: it is the upward pressure of the air, which, while the thumb is kept on the top, is not counterbalanced by any downward pressure: therefore it keeps the water suspended in the tube.

Take this ale-glass, fill it with water, and cover it with a piece of writing-paper: then place your hand evenly over the paper, so as to hold it very tight about the edge of the glass; you may then invert the glass, and take away your hand without any danger of the water's falling out.

E. Is the water sustained by the upward pressure of the air?

F. The upward pressure of the air against the paper sustains the weight of water, and prevents its falling.

You have seen the instrument used for tasting beer or wine?

E. Yes; it is a tin tube, that holds about half a pint, into which very small tubes are inserted at top and bottom.

F. The longer one is put into the hole made for the vent-peg, and then, by drawing out the air from it, beer or wine is forced into the large part of the tube; then by putting the thumb or finger on the upper part, the whole instrument may be taken out of the cask, and removed anywhere, for the pressure of the air against the bottom surface of the lower tube keeps the liquor from running out; but the moment the thumb is taken from the top, the liquor descends by the downward pressure of the air.

C. Is it for a similar reason that vent-holes are made in casks?

F. It is: for when a cask is full, and perfectly close, there is no downward pressure, and therefore the air, pressing against the mouth of the cock, keeps the liquor from running out; a hole made at the top of the cask admits the external pressure of the air, by which the liquor is forced out. In large casks of ale or porter, where the demand is not very great, the vent-hole need seldom be used, for a certain portion of the air contained

in the liquor escapes, and, being lighter than the beer, ascends to the top, by which a pressure is created without the assistance of the external air.

C. Do fluids experience friction as they flow?

F. Yes: a stream is always less rapid at the sides than in the middle of a river, because it experiences friction against the banks and shallow bottom. If a fine tube is fitted to a conical horizontal tube, and dipped into water—(the letter T represents the arrangement,) and water flows along the horizontal tube; its friction against the air at the orifice of the smaller tube will draw the air after it: the water will then rise in the smaller tube, and eventually flow along with the other water. The same happens with a vertical arrangement.

CONVERSATION IV.

Of the Lateral Pressure of Fluids.

F. It is time now to advance another step, and to show that the *lateral* or *side* pressure is equal to the perpendicular pressure.

E. If the upward pressure is equal to the downward, and the side pressure is also equal to it, then the pressure is equal in all directions.

F. You are right. Though the side direction may be varied in many ways, yet there are only the upward, downward, and lateral directions. The two former we have shown are equal. That the side pressure is equal to the perpendicular pressure downwards is demonstrated by a very easy experiment.

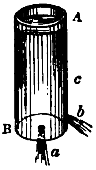


Fig. 6.

A B is a vessel filled with water, having two small equal orifices, or holes, *a b*, bored with the same tool, one at the side, and the other in the bottom; if these holes are opened at the same instant, and the water suffered to run into two glasses, they will be found, in a given time, to have discharged equal quantities of water; which is a clear proof that the water presses sideways as forcibly as it does downwards.

C. Are we then to take it as a general principle, that fluids press in every possible direction?

F. This, I think, our experiments have proved; but you must not forget that it is only true upon the supposition that the *perpendicular heights are equal.* For in the last experiment, if the hole *b* had been bored an inch or two higher in the side of the vessel, as at *c*, the quantity of water running out at *a* would have been greater than that at *b;* and much greater would it

have been, if the hole had been bored at four or five inches above the bottom of the vessel.

Fig. 7.

This subject of pressure may be farther illustrated. At the bottom of this tube *z y*, open at both ends, I have tied a piece of bladder, and have poured in water till it stands at the mark *x*. Owing to the pressure of the water, the bladder is convex, that is, bent outwards; dip it into the jar (fig. 4, page 148.), the bladder is still convex: thrust it gently down; the surface of the water in the tube is now even with that in the jar.

E. It is; and the bladder at the bottom is become flat.

F. The perpendicular depths being equal, the pressure upwards is equal to that downwards, and the water in the tube is exactly balanced by the water in the jar. Let the tube be thrust deeper into the water.

C. Now the bladder is bent upwards.

F. The upward pressure is estimated by the perpendicular depth of the water in the jar, measured from the surface to the bottom of the tube; but the pressure downwards must be estimated by the perpendicular height of the water in the tube, which being less than the former, the pressure upwards in the same proportion overcomes that downwards, and forces up the bladder into the position as you see it. This and the following experiment are some of the best that can be exhibited in proof of the upward pressure of fluids.

Dip an open end of a tube, having a very narrow bore, into a vessel of quicksilver; then, stopping the upper orifice with the finger, lift up the tube out of the vessel, and you will see a sort of column of quicksilver hanging at the lower end, which, when dipped in water lower than 14 times its own length, will, upon removing the finger, be pressed upwards into the tube.

E. Why do you fix upon 14 times the depth?

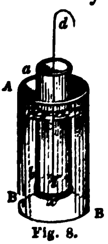


Fig. 8.

F. Because quicksilver is 14 times heavier than water. Upon this principle of the upper pressure, lead or any other metal may be made to swim in water. A B is a vessel of water, and *a b* is a glass tube, open throughout; *d* is a string, by which a flat piece of lead *x* may be held fast to the bottom of the tube. To prevent the water from getting in between the lead and the glass, a piece of wet leather is first put over the lead.

In this situation, let the tube be immersed in the vessel of water, and if it be plunged to the depth of about eleven times the thickness of the lead before the string be let go, the lead will not fall from the tube, but be kept adhering to it by the upward pressure below it.

E. Is lead 11 times heavier than water?

F. It is between 11 and 12 times heavier; and, therefore, to make the experiment sure, the tube should be plunged somewhat deeper than 11 times the thickness of the lead.

C. Is it not owing to the wet leather rather than to the upward pressure, that the lead sticks to the tube?

F. If that be the case, it will remain fixed if I draw up the tube an inch or two higher:—I will try it.

E. It has fallen off.

F. Because, when the tube was raised, the upward pressure was diminished so much as to become too small to balance the weight of the lead. But if the adhering together of the lead and tube had been caused by the leather, there would be no reason why it should not operate the same at six or nine times the depth of the lead's thickness, as well as at 11 or 12 times that thickness.

CONVERSATION V.

Of the Hydrostatic Paradox.

E. You are to explain a paradox to-day: I thought natural philosophy had excluded all paradoxes.

F. Dr. Johnson has given this definition of a paradox, "an assertion contrary to appearances:" now the assertion which I am to refer you to is, *that any quantity of water, however small, may be made to balance any quantity, however large.* That a pound of water, for instance, should, without any mechanical advantage, be made to support ten pounds, or a hundred, or even a ton weight, seems at first incredible; certainly it is contrary to what one should expect, and on that account the experiment to show this fact has usually been called the hydrostatic paradox.

C. It does appear unaccountable: I hope the experiments may be very easy to be understood.

F. Many have been invented for the purpose;—OBGH is a glass vessel, consisting of two tubes of very different sizes, joined together, and freely communicating with one another. Let water be poured in at H, which will pass through the joining of the tubes, and rise in the wide one to the same height exactly as it stands in the smaller: which shows that the small column of water in DG balances the large one in the other tube. This will be the case if the quantity of water in the small tube be

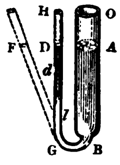


Fig. 9.

a thousand or a million times less than the quantity in the larger one.

If the smaller tube be bent in any oblique direction, as G F, the water will stand at F, that is, on the same level as it stands at A. This would be the case, if, instead of two tubes, there were any given number of them connected together at B, and varied in all kinds of oblique directions, the water would be on a level in them all; that is, the *perpendicular height* of the water would be the same.

C. This does not quite satisfy me; because it appears that a great part of the water in the large tube is supported by the parts B about the bottom, and therefore that the water in the smaller tube only sustains the pressure of a column of water, the diameter of which is equal to its own diameter.

F. This would be the case if the pressure of fluids were only downwards, but we have shown that it acts in all directions; and, therefore, the pressure of the parts near the side of the tube acts against the column in the middle, which you suppose is the only part of the water sustained by that contained in the small tube; consequently, the smaller quantity of water in D B sustains the larger one in A B.

Let us try another experiment.

A B C and A B C are two vessels, having their bottoms D *d* and D *d* exactly equal, but the contents of one vessel are twenty times greater than the other; that is, the first figure,

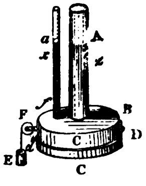


Fig. 10.

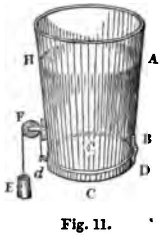


Fig. 11.

when filled up to A, will hold but one pint of water; whereas the second, when filled to the same height, will hold twenty pints. Brass bottoms, C C, are fitted exactly to each vessel, and made water-tight by pieces of wet leather. Each bottom is joined to its vessel by a hinge D, so that it opens downwards like the lid of a box. By means of a little hook *d*, a pulley F, and a weight E, the bottom is kept close to the vessel, and will hold a certain quantity of water.

E. That is, till the *weight* of the water overcome the weight E.

F. No; not till the *weight*, but till the *pressure* of the water overcome the weight E.

Now hold the second vessel upright in your hands, while I gradually pour water into it with a funnel; the pressure bears down the bottom, and, of course, raises the weight, and a small quantity of the water escapes. Let us mark the height H A, at which the surface of the water stood in the vessel when the bottom began to give way.

Try the other vessel in the same manner, and we shall see that when the water rises to A, that is, to just the same height in this vessel as in the former, the bottom will also give way, as it did in the other case. Thus equal weights are overcome in the one case by twenty pints of water, and in the other by a single pint. The same would hold good if the difference were greater or less in any given proportion.

E. What is the reason of this, papa?

F. It depends upon two principles, with which you are now acquainted. The first is, that fluids press equally in all directions; and the second is, that action and reaction are equal and contrary to each other.* The water, therefore, below the fixed part B *f* will press as much upwards against the inner surface, by the action of the small column, as it would by a column of the *same height*, and of any other diameter whatsoever; and since action and reaction are equal and contrary, the action against the inner surface B *f* will cause an equal reaction of the water in the cavity B *f* C D against the bottom C; consequently the pressure upon the bottom of the first figure will be as great as it was upon the same part of the second (p. 156.).

C. Can you prove by experiment that there is this upward pressure against the inner surface B *c f*?

F. Very easily: suppose at *f* there were a little cork, to which a small string was fixed; I might place a tube over the cork, and then draw it out, the consequence of which would be, that the water in the vessel would force itself into the tube, and stand as high in it as it does in the vessel. Would not this experiment prove that there was this upward pressure against B *f*?

C. It would; and I can easily conceive that if other tubes were placed, in the same manner, in different parts of B *f*, the same effect would be produced.

F. Then you must admit that the action against B *f*, or,

* See Mechanics, Conversation XI.

which is the same thing, the reaction against C, that is, the pressure of the water against the bottom, is equally as great as it would be if the vessel were as large in every part as it is at the bottom, and the water stood level to the height A *a*.

C. Yes, I do; because, if tubes were placed in every part of B *f*, the same effect would be produced in them all, as in the single one at *f*; but, if the whole surface were covered with small tubes, there would then be little or no difference between the two vessels. See Figs. 10. and 11.

F. There would be no difference, provided you kept filling the large tube, so that the water should stand in them all at the same level A *a*. Otherwise, the introduction of a single tube *a f*, would make a material difference: for though the water in A C would overcome the weight E, yet if with my hand I prevent any of the water from running out till I have taken out the cork, and suffered the water to force itself out of the vessel into the small tube, I may remove my hand with safety; for the water will not overcome the weight now, though there is certainly the same quantity of water in it as there was before the little tube *a f* was inserted.

E. I think I see the reason of this: the water stood as high as A *a* before the little tube was introduced, but now it stands at the level *x x*; and you told us yesterday that the pressures were only equal, provided the *perpendicular heights were also equal.*

F. I am glad to find you so attentive to what I say. In order that the pressure may overcome the weight E, you must put in more water till it rise to the level A *a*, and now you see the weight rises, and the water flows out.

I will put another tube, and the water rushing into that causes the level to descend again to *x x*, and I must put more water in to bring the level up to A *a* before it can overcome the weight E. What I have shown in these two cases will hold true in all, supposing you fill the cover with tubes.

C. I see, then, that it is the difference of the perpendicular heights which causes the difference of pressure, and can now fully comprehend the reason why a pint of water may be made to balance or support a hogshead; or, in the words with which you set out, that *any quantity of water, however small, may be made to balance and support any other quantity, however large.*

F. What has been proved with regard to water, may be shown to hold with regard to wine, or oil, or any other fluid. But the experiment will not answer if different fluids are made use of, as water and oil together.

CONVERSATION VI.

Of the Hydrostatic Bellows.

F. I think we have made it sufficiently clear that the pressure of fluids *of the same kind* is always proportional to the area of the base multiplied into the perpendicular height at which the fluid stands, without any regard to the form of the vessel, or the quantity of fluid contained in it.

E. But it still appears very mysterious to me, that a pint of water in the narrow vessel (Fig. 10.) should have an equal pressure with the 20 pints in the next vessel. You will not say that one pint weighs as much as the 20.

F. Your objection is proper. The pressure of the water upon the bottom c c does not in the least alter the weight of the vessel and water considered as one mass; for the action and reaction which cause the *pressure*, destroy one another with respect to the *weight* of the vessel, which is as much sustained by the action upwards as it is pressed by the reaction downwards.

The *pressure* of fluids differs from the gravity or weight in this respect: the *weight* is according to the *quantity*; but the *pressure* is according to the *perpendicular height.*

C. Suppose both vessels were filled with any solid substance, would the effect produced be very different?

F. If the water were changed into ice, for instance, the pressure upon the bottom of the smaller vessel would be much less than that upon the larger.

Here is another instrument to show you that a very few ounces of water will lift up and sustain a large weight.

E. What is the instrument called?

F. It is made like common bellows, only without valves, and writers have given it the name of the hydrostatic bellows. This small tin pipe *e o p* communicates with the inside of the bellows. At present the upper and lower board are kept close to one another with the weight *w*. Pour this half pint of water into the tube.

C. It has separated the boards and lifted up the weight.

F. Thus you see that seven or eight ounces of water have raised and continue to sustain a weight of 56 lb. By diminishing the bore of the pipe and increasing its

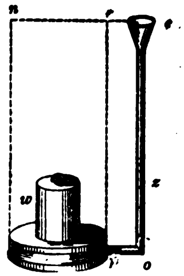


Fig. 12.

length, the same, or even a smaller, quantity of water would raise a much larger weight.

C. How do you find the weight that can be raised by this small quantity of water?

F. Fill the bellows with water, the boards of which, when distended, are three inches asunder. I will screw in the pipe. As there is no pressure upon the bellows, the water stands in the pipe at the same level with that in the bellows at *z*.

Now place weights on the upper board till the water ascend exactly to the top of the pipe *e*: these weights express the weight of a pillar, or column of water, the base of which is equal to the area of the lower board of the bellows, and the height equal to the distance of the upper board from the top of the pipe.

E. Will you make the experiment?

F. Your brother shall first make the calculation.

C. But I must look to you for assistance.

F. You will require very little of my help. Measure the diameter of the bellows, and the perpendicular height of the pipe from the upper board.

C. The bellows are circular, and 12 inches in diameter; the height of the pipe is 36 inches.

F. Well: you have to find the solid content of a cylinder of these dimensions; that is, the area of the base multiplied by the height.

C. To find the area I multiply the square of twelve inches, that is, 144, by the decimals ·7854, and the product is 113 nearly, the number of square inches in the area of the bottom board of the bellows. And 113 multiplied by 36 inches, the length of the pipe, gives 4068, the number of cubic inches in such a cylinder; this divided by 1728 (the number of cubic inches in a cubic foot) leaves a quotient of 2·3 cubic feet, the solid contents of the cylinder. Still I have not the weight of the water.

F. The weight of pure water is equal in all parts of the known world, and a cubical foot of it weighs 1000 ounces, or 62½ pounds avoirdupois, or nearly six-elevenths of a hundred weight.

C. Then such a cylinder of water, as we have been conversing about, weighs about 2300 ounces, or 144 pounds nearly.

E. Let us now see if the experiment answers to Charles's calculation.

F. Put the weights on carefully, or you will dash the water out at the top of the pipe, and I dare say that you will find the fact agrees with the theory.

C. If instead of this pipe one double the length was used, would the water sustain a double weight?

F. It would; and a pipe three or four times the length would sustain three or four times greater weights.

C. Are there then no limits to this kind of experiment, except those which arise from the difficulty of acquiring length in the pipe?

F. The bursting of the bellows would soon determine the limit of the experiment. Dr. Goldsmith says, that he once saw a strong hogshead split by this means. A strong small tube made of tin, about 20 feet long, was cemented into the bung-hole, and then water was poured in to fill the cask; when it was full and the water had risen to within about a foot of the top of the tube, the vessel burst with prodigious force.

E. It is very difficult to conceive how this pressure acts with such power.

F. The water at *o* is pressed with a force proportional to the perpendicular altitude *e o;* this pressure is communicated horizontally in the direction *o p q*, and the pressure so communicated acts, as you know, equally in all directions: the pressure, therefore, downwards upon the bottom of the bellows is just the same as it would be if *p q n r* were a cylinder of water.

The experiment made on the bellows might, for want of such instrument, be made by means of a bladder in a box with a movable lid.

E. Has this property of Hydrostatics been applied to any practical purposes?

F. The knowledge of it is of vast importance in the concerns of life. On this principle a press of immense power has been formed, which we shall describe (see Conversation XX), after you are acquainted with the nature and structure of valves, and which is used in many sea-port towns for pressing into small compass hay and other commodities, for stowage on board ship, but which in their natural state would take up too much space. The same property is also applied to proving cables, by tearing them; and to the pulling up of trees.

CONVERSATION VII.

Of the Pressure of Fluids against the Sides of Vessels.

F. Do you recollect, Charles, the law by which you calculated the accelerated motion of falling bodies?*

C. Yes: the space described increases in the same proportion as the odd numbers 1, 3, 5, 7, 9, &c.; that is, if at the end of

* See Mechanics, Conversations VII. and VIII.

one second of time the body has been carried through a vertical space of 16 feet, then in the next second it will descend three times 16, or 48 feet; in the third it will descend five times 16 feet, and in the next seven times 16 feet, and so on, continually increasing according to the same law.

F. Well, then, what I am going to tell you will tend to impress the rule still more strongly on your memory.

The pressure of fluids against the sides of any vessel increases in the same proportion, and is governed by the same laws.

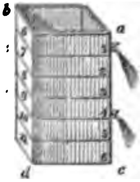


Fig. 13.

Suppose *a b c d* to be a cubical vessel filled with water or any other fluid, and one of the sides to be accurately divided into any number of equal parts by the lines 1, 7; 2, 8; 3, 9; &c. Now if the pressure of the water upon the part of the vessel *a* 1 *b* 7 be equal to an ounce or a pound, then the pressure upon the part 1, 2, 7, 8, will be equal to three ounces, or three pounds; and the pressure upon the part 2, 3, 8, 9, will be equal to five ounces or pounds, and so on.

C. Then I see the reason why the other part of the rule holds true, viz. that the pressure against the whole side must vary as the square of the depth of the vessel.

F. Explain to us the reason.

C. The pressure upon the *first* part being 1, and that upon the *second* 3, and that upon the *third* 5; then the pressure upon the first and second taken together is by addition 4; upon the first, second, and third it must be 9; and upon the first, second, third and fourth, it will be 16: but 4, 9, 16, are the squares of 2, 3, 4.

E. And the pressure upon the whole side *a b c d* must be 36 times greater than that upon the small part *a* 1, *b* 7.

C. And if there are three vessels, for instance, of equal width, whose depths are as 1, 2, and 3, the pressure against the side of the second will be four times greater than that against the first; and the pressure against the side of the third will be nine times greater than that against the first.

F. You are right; the beautiful simplicity of the rule, and its being the same by which the accelerating velocity of falling bodies is governed, will make it impossible that you should hereafter forget it.

The use that I shall hereafter call you to make of the rule, induces me to put a question to Emma.

In two canals of equal section, one 5 feet deep, and the other

15, what difference of pressure will there be against the sides of these canals?

E. The pressure against the one will be as the square of 5, or 25; that against the other will be as the square of 15, or 225; now the latter number divided by the former gives 9 as a quotient, which shows that the pressure against the sides of the deep canal is nine times greater than that against the sides of the shallow one.

C. You have explained the manner of estimating the pressure of fluids against the sides of a vessel; by what rule are we to find the pressure upon the bottom?

F. In such vessels, that is, where the sides are perpendicular to the bottom, and the bottom parallel to the horizon, *the pressure will be equal to the weight of the fluid.*

E. If then the vessel hold an imperial gallon of water, which weighs ten pounds, and if the bottom were made movable, would a weight of ten pounds keep the water in the vessel?

F. It would: for then there would be an equilibrium between the pressure of the water and the weight. And the pressure upon any one side is equal to half the pressure upon the bottom; that is, provided the bottom and sides are equal to one another.

C. Pray, sir, explain how that is made out.

F. The pressure upon the bottom is, as we have shown, equal to the weight of the fluid. But we have also shown that the pressure on the sides becomes less and less continually, till at the surface it is nothing. Since, then, the pressure upon the bottom is truly represented by the area of the base multiplied into the altitude of the vessel, the pressure upon the side will be represented by the base multiplied into half the altitude.

E. Is the pressure upon the four sides equal to twice the pressure upon the bottom?

F. It is; consequently, the pressure of any fluid upon the bottom and four sides of a cubical vessel is equal to three times the weight of the fluid.

Can you, Charles, tell me the difference between the *weight* and the *pressure* of a conical vessel of water standing on its base?

C. The *weight* of a conical vessel of any fluid is found by multiplying the area of the base by $\frac{1}{3}$ of its height, and then by the specific gravity*: but the *pressure* is found by multiplying the

* The rule for finding the solidity of a cone or a pyramid is this: —"Multiply the area of the base by one third of the height, and the product will be the solidity."—See Hutton's or Bonnycastle's Mensuration; or, an "Introduction to the Arts and Sciences," by the author of SCIENTIFIC DIALOGUES, art. *Mensuration.*

base by the specific gravity, and whole height; therefore the pressure upon the base will be equal to three times the weight.

CONVERSATION VIII.

Of the Motion of Fluids.

F. We will now consider the pressure of fluids with regard to the motion of them through spouting-pipes, which is subject to the same law.

If the pipes at 1 and 4 (fig. 13. p. 162.) will be equal in size and length, the discharge of water by the pipe at 4 will be double that at 1. Because the velocity with which water spouts out at a hole in the side or bottom of a vessel is as the *square root* of the distance of the hole below the surface of the water.

E. I remember that the square root of any number is that which, being multiplied into itself, produces the said number. Thus the square root of 1 is 1; but of 4 it is 2; of 9 it is 3; of 16 it is 4; and of 25 it is 5; and so on.

C. Then if you had a tall vessel of water with a cock inserted within a foot of the top, and you wished to draw the liquor off three times faster than it could be done with that, what would you do?

F. I might take another cock of the same size, and insert it into the barrel at nine feet distance from the surface, and the thing required would be done.

E. Is this the reason why water runs so slowly out of the cistern when it is nearly empty, in comparison of what it does when the cistern is just full?

F. It is; because the more water there is in the cistern, the greater the pressure upon the part where the cock is inserted; and the greater the pressure, the greater the velocity, and consequently the greater the quantity of water that is drawn off in the same time.

In some large barrels there are two holes for cocks, the one about the middle of the cask, the other at the bottom: now if, when the vessel is full, you draw the beer or wine from both cocks at once, you will find that the lower one gives out the liquor much the faster.

C. In what proportion?

F. As the square root of 2 is greater than that of 1; that is, while you have a quart from the upper cock, nearly three pints would run from the lower one, provided the vessel were full.

E. Are we then to understand that the *pressure* against the side of a vessel increases in proportion to the *square* of the depth;

but the *velocity of a spouting pipe*, which depends upon the pressure at the orifice itself, increases only as the *square root* of the depth?

F. That is the proper distinction.

C. Is not the velocity of water, running out of a vessel that empties itself, continually decreasing?

F. Certainly: because, in proportion to the quantity drawn off, the surface descends, and consequently the perpendicular depths become less and less.

The spaces described by the descending surface, in equal proportions of time, are as the odd numbers 1, 3, 5, 7, 9, &c., taken backwards.

E. If the height of a vessel filled with any fluid be divided into 25 parts, and in a given space of time, as a minute, the surface descend through nine of those parts, will it, in the next minute, descend through seven of those parts, in the third minute five, in the fourth three, and in the fifth one?

F. This is the law, and from it have been invented *clepsydræ*, or water-clocks, which were to a certain extent used before the invention of clocks and watches, and even now are found at times serviceable; as for instance at the Observatory in Liverpool, where a water-clock is used to give regular motion to the equatorial telescope, so that the same star is continued in the field of the telescope, notwithstanding the movement of the earth on its axis?

C. How are water-clocks constructed?

F. Take a cylindrical vessel, and having ascertained the time it will require to empty itself, then divide, by lines, the surface into portions, which are to one another as the odd numbers 1, 3, 5, 7, &c.

E. Suppose the vessel require six hours to empty itself, how must it be divided?

F. It must be first divided into 36 equal parts; then, beginning from the surface, take eleven of those parts for the first hour, nine for the second, seven for the third, five for the fourth, three for the fifth, and one for the sixth, and you will find that the surface of the water will descend regularly through each of those divisions in an hour.

I believe both of you have seen the locks that are constructed on the river Lea?

C. Yes; and I have wondered why the floodgates were made of such an enormous thickness.

F. But after what you have heard respecting the pressure of fluids, you will see the necessity there is for the great strength employed.

C. I do; for sometimes the height of the water is 20 or 30 times greater on one side of the gates than it is on the other, therefore the pressure will be 400 or even 900 times greater against one side than it is against the other.

And I also can well conceive that there was good reason for the destructive violence, with which the water escaped from the Holmfirth reservoirs, and also from those near Bury in Lancashire, during this year. And I am not at all surprised at the wreck and ruin that occurred at Chamouni, and, on a greater or less scale, throughout England and the Continent of Europe,—from the unprecedented rains of the memorable autumn of 1852.

E. How are the gates opened when such a weight presses against them?

F. There is scarcely any power by which they could be moved when this weight of water is against them; therefore there are sluices by the side, which, being drawn up, the water gets away and passes into the basin till it becomes level on both sides; then the gates are opened with the greatest ease, because the pressure being equal on both sides, a small force applied will be sufficient to overcome the friction of the hinges, or other trifling obstacles.

C. Is it this great pressure that sometimes beats down the banks of rivers?

F. It is; for if the banks of a river or canal do not increase in strength in the proportion of the square of the depth, they cannot stand. Sometimes the water in a river will insinuate itself through the bank near the bottom; and if the weight of the bank be not equal to that of the water, it will assuredly be torn up, perhaps with great violence.

I will make the matter clear by a drawing. Suppose this figure be a section of a river, and *c* a crevice or drain made by time under the bank *g*; by what we have shown before, the upward pressure of the water in that drain is equal to the downward pressure of the water in the river; therefore, if that part of the bank be not as heavy as a column of water the same height and width, it must be torn up by the force of the pressure.

Fig. 14.

C. Is there no method of securing leaks that happen in the embankments of rivers?

F. The only method is that called *puddling*. If *n* be the bank of a canal in which a leak is discovered, the water must be first drawn off before the leak, and a trench 18 or 20 inches wide dug lengthwise along the side of the canal, and deeper than the bottom of the canal: this is filled, by a little at a time, with clay or loam reduced into a semi-fluid state by mixing it with water: when the first layer, which is seldom above six or eight inches deep, is nearly dry, another is worked in the same manner till the whole is filled. By this means, if the operation be performed by skilful hands, and time be allowed for all the parts to dry and cohere, the bank becomes strong and impenetrable.

CONVERSATION IX.

Of the Motion of Fluids.

F. I will now show you an experiment, by which you will observe the uniformity of Nature's operations in regard to spouting fluids. Let A B represent a tall vessel of water, kept full during the experiments. From the centre of this vessel I have drawn a semicircle, the diameter of which is the height of the vessel A B. I have drawn three lines perpendicular to the vessel, *d* 2 from the centre of the vessel; *c* 1, *a* 5, at equal distances from the centre, the one above and the other below it. By taking out the plug from the centre, you will see that the water spouts to M. Take your compasses and you will find that the distance N M is exactly double the length of *d* 2. I will now stop this plug and open the next below.

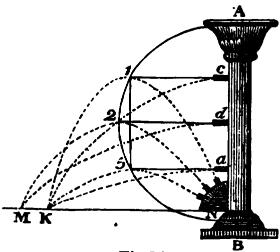


Fig. 15.

C. The water reaches to K, which is double the length of *a* 5.

F. Try in the same manner the pipe *c*.

C. It falls at the same spot K, as it did from the lower one.

F. Because the lines *c* 1 and *a* 5 being equally distant from the centre of the semicircle, they are equal to one another.

E. Then N K is the double of *c* 1 as well as of *a* 5.

F. It is. The general rule deduced from these experiments, is that the horizontal distance to which a fluid will spout from a horizontal pipe, in any part of the side of an upright vessel below the surface of the fluid, is equal to twice the length of a

perpendicular to the side of the vessel, drawn from the mouth of the pipe to a semicircle described upon the altitude of the vessel.

Can you, Charles, tell me in what part the pipe should be placed, in order that the fluid should spout the farthest possible?

C. In the centre: for the line *d* 2 seems to be the greatest of all the lines that can be drawn from the vessel to the curved line.

F. Yes, it is demonstrable by geometry that this is the case; and that lines at equal distances from the centre, above and below, are also equal to each other.

E. Then, in all cases, if pipes are placed equally distant from the centre, they will spout to the same point?

F. They will. Instead of horizontal pipes, I will fix three others near N, which shall point obliquely upwards at different angles; one at 22° 30′, the second at 45°, and the third at 67° 30′, and you will see that, when I open the cocks, the water will cut the curve line nearly, but not accurately, in those parts to which the horizontal lines were drawn.

C. That which spouts from the centre is thrown to the point M, as it was from the centre horizontal pipe. The two others fall on the point K, on which the upper and lower horizontal pipes ejected the stream.

E. I thought the water from the upper cock did not reach so high as the mark.

F. It did not. The reason is, that it had to pass through a larger body of air, and the resistance from that retarded the water, and prevented it from ascending to the point to which it would have ascended if the air had been taken away.

While we are on this subject, I will just mention, that as you see the water-spouts the farthest when the pipe is elevated to an angle of 45°, so a gun, cannon, &c. will project a bullet the farthest, if it be elevated to an angle of 45°.

C. Will a cannon carry a ball to equal distances if it be elevated at angles equally distant from 45°, the one above and the other below?

F. It will, in theory: but owing to the great resistance which very swift motions meet with from the air, there must be allowances made for some considerable variation between theory and practice.

A regard to this will explain the reason why water will not rise so high in a jet as it does in a tube.

E. I do not know what this means.

F. Turn to the figure in p. 155; the water in the small tube rises to a level with that in the larger one; now, if the tube H G

were broken off at *t*, the water would spout up like a fountain, but not so high as it stands in the tube, perhaps no higher than to *d*.

C. Is that owing wholly to the resistance of the air?

F. It is to be ascribed to the resistance which the water meets with from the air, and to the force of gravity, which has a tendency to retard the motion of the stream.

E. Why do fountains sometimes play higher and sometimes lower?

F. There is a reservoir of water, from which a pipe communicates with the jet in the fountain; and according as the water in the reservoir is higher or lower, the height to which the fountain plays is regulated.

From what you have already learnt on this subject, you will be able to know how London and other places are supplied with water.

C. London is, I believe, partly supplied from the New River, but I do not know in what manner.

F. The New River is a stream of water that comes from Ware, in Hertfordshire; it runs into a reservoir situated on the high ground near Islington. From this reservoir pipes are laid into those parts of town that have their water from the New River, and through these pipes the water flows into cisterns belonging to different houses.

E. Then the reservoir in Islington must be higher than the cisterns in London.

F. Certainly; because water will not rise above its level. Thus you see that water may be carried to any distance, and houses, on different sides of a deep valley, may be supplied by water from the same spring-head. You must remember that if the valleys are very deep, the pipes must be exceedingly strong near the bottom, because the pressure increases in the rapid proportion of the odd numbers, 1, 3, 5, 7, &c., and therefore, unless the strength of the wood or iron be increased in the same proportion, the pipes will be continually bursting.

E. You told me the other day that the large mound of earth, for it appears nothing else, near the end of Tottenham Court Road, was intended as a reservoir for the New River.

F. What appears to you, and others who pass by it, only as a mound of earth, is an exceedingly large basin, capable of containing a great many thousand hogsheads of water.

C. How do they get the water into it?

F. At Islington, near the New River Head, is made a large reservoir upon some very high ground, into which, by means of a steam-engine, they constantly throw water from the New

River. This reservoir being higher than that in Tottenham Court Road, nothing more is necessary than to lay pipes from Islington to that place, in order to keep it constantly full of water.

By this contrivance the New River Company are able to extend their business to other parts of London, to which their previous head of water could not reach.

C. The weight of water in this place must be immensely great.

F. It must; and therefore you observe what a thickness the mound of earth against the wall is at the bottom, and that it diminishes towards the top as the pressure becomes less and less.

E. Would not the consequences be very serious if the water were to insinuate itself through the earth at the bottom?

F. If such an accident were to happen when the reservoir was full of water, it would probably tear up the works, and do incredible mischief. To prevent this, the vast bank of earth is sloped within as well as without; it is then covered with a strong coating of clay; after this it is built up with a very thick brick wall, which is carefully tarrassed over, so that the whole mass is as firm and compact as a glass bottle.

C. I see, then, that to get water to run above its original level, some other pressure besides its own must be added.

F. Yes; but there is a case in which *momentum* acts the part of this other pressure—in the hydraulic ram. This instrument is so constructed that the escape of the water is suddenly cut off: the momentum cannot be annihilated in a moment, and therefore exercises itself against the sides of the tube. If a small orifice is at this instant opened in the latter, the water will leap beyond the level of the original reservoir; as, for instance, a column of water from a source 20 ft. high may mount to a cistern 150 ft. high, but for one gallon raised, eleven are wasted. This waste, in many cases, is a matter of no importance. The machine consists of a closed rectangular vessel, with an exit-pipe leading to an air-vessel, and another to the cistern, and each furnished with a valve. The pressure of the water is equal to the area of the pipe and the height of the fall, and it closes the valve of the cistern-pipe, and enters the air-vessel and compresses the air. The valves now alternate: the opened one is closed by the reaction of the compressed air, and the closed one opens; and the elasticity of the air, in the act of expanding, forces the water up to the cistern very much on the same principle that the compressed air operates in a fire-engine.

CONVERSATION X.

Of the Specific Gravities of Bodies.

E. What is the reason, papa, that some bodies, as lead or iron, sink in water, while others, as wood, swim?

F. Those bodies that are heavier than water will sink in it, but those that are lighter will swim.

E. I do not quite comprehend your meaning; a pound of wood, another of water, and another of lead, are all equally heavy. For Charles played me a trick the other day: he suddenly asked which was heavier, a pound of lead or a pound of feathers? I said the lead, and Charles laughed at me, and said that both were the same, and, of course, so they were; for a pound is a pound, whether it be of lead or of feathers.

F. But, Emma dear, suppose you and I have our laugh at Charles, and tell him that a pound of feathers is actually heavier than a pound of lead.

C. No, papa, you are joking; it cannot be.

F. But it is; for the pound of feathers is much larger in bulk, and is supported by a much larger bulk of the fluid, namely, air, in which it is weighed, and you will find that if you compress a pound of feathers into a very small bulk, they would weigh more than a pound, and so would outweigh the lead. But you will understand this better as we go on. Do you know how much water goes to a pound?

C. Yes, about a pint.

F. Do you think that a pint of lead would weigh a pound only?

C. Oh no; that would weigh a great deal more. I do not believe that the 14 pounds weight below stairs is much larger than a pint measure.

F. Yes it is, by about a fourth part: the same measure that contains one pound of water would, however, contain upwards of 11 pounds of lead; but it would contain nearly 14 pounds of quicksilver, which, you know, I could as easily pour into the vessel as if it were water.

Here are two cups of equal size: fill the one with water, and I will fill the other with quicksilver. Take the cups in your hand; which is the heavier?

C. The quicksilver by much.

F. But the two cups are of equal size.

E. Then there must be equal quantities of water and quicksilver.

F. They are equal in bulk.

C. But very unequal in weight: shall I try how much heavier the one is than the other?

F. If you please. In what manner will you ascertain the matter?

C. I will pour the quicksilver first into the scale and weigh it; afterwards do the same with the water; and divide the former by the latter; will not that give the result?

F. Yes, it will: or you may make the experiment in this method:

Here is a small phial, that weighs, now it is empty, an ounce; fill it with pure rain water, and the weight of the whole is two ounces.

C. Then it contains one ounce of water.

F. Pour out the water, and let it be well dried both within and without: fill it now very accurately with quicksilver, and weigh it again.

E. It weighs nearly 15 ounces: but, as the bottle weighs one ounce, the quicksilver weighs nearly 14 ounces.

F. What do you infer from this, Charles?

C. That the quicksilver is nearly 14 times heavier than water.

F. I will now pour away the quicksilver, and fill the phial with pure spirits of wine, or, as the chemists call it, with *alcohol.*

E. It does not weigh two ounces now; consequently, the fluid does not weigh an ounce. The alcohol is, then, lighter than the water.

F. By these means, which you cannot fail of understanding, we have obtained the *comparative weights* of three fluids: philosophers, as I have before told you, call these comparative weights the *specific gravities* of the fluids: they have agreed also to make pure rain water the standard to which they refer the comparative weights of all other bodies, whether solid or fluid.

C. Is there any particular reason why they prefer water to every other substance?

F. I told you a few days ago, that rain water, if very pure, is of the same weight in all parts of the world; and, what is very remarkable, a cubic foot of it weighs exactly a thousand ounces avoirdupois: on these accounts it is admirably adapted for a standard, because you can at once tell the weight of a cubic foot of any other substance, if you know its specific gravity.

E. Then a cubic foot of quicksilver weighs nearly 14,000 ounces.

F. Yes; it will weigh 13,596 ounces; and a cubic foot of lead will weigh 11,350 ounces.

CONVERSATION XI.

Of the Specific Gravities of Bodies.

F. You now understand that the specific gravities of different bodies depend upon their density, and that water is made use of as a medium to discover the different specific gravities of different bodies; and also as a standard, to which they may be all referred.

Here are three pieces of different kinds of wood, which I will put into this vessel of water: one sinks to the bottom; a second remains in any position of the water in which it is placed; and the third swims on the water with more than half of the substance above its surface.

C. The first, then, is heavier than the water; the second is of the same weight with an equal bulk of the fluid; and the third is lighter.

F. Since fluids press in all directions, a solid that is immersed in water sustains a pressure on all sides, which is increased in proportion to the height of the fluid above the solid.

E. That seems natural, but an experiment would fix it better in the mind.

F. Tie a leathern bag to the end of a glass tube, and pour in some quicksilver. Dip the bag in water, and the upward pressure of the fluid will raise the quicksilver in the tube, the ascent of which will be higher or lower in proportion to the height of the water above the bag.

Fig. 7.

E. I now understand that, the upper part of the tube being empty, or, at least, only filled with air, the upward pressure of the water against the bag must be greater than the downward pressure of the air; and that, as the pressure increases according to the depth, therefore the mercury must keep rising in the tube.

What is the reason that a body heavier than water, as a stone, sinks to the bottom, if the pressure upwards is always equal to that downwards?

F. This is a very proper question. The stone endeavours to descend by the force of gravity; but it cannot descend without moving away as much of the water as is equal to the bulk of the stone; therefore it is resisted, or pressed upwards, by a force equal to the weight of as much water as is equal in magnitude to the bulk of the stone; but the weight of the water is less than that of the stone, consequently the force pressing against it upwards is *less* than its tendency downwards, and therefore it will sink with the *difference* of these two forces.

You will now be at no loss to understand the reason why bodies lighter than water swim.

C. The water being heavier, the force upwards is greater than the natural gravity of the body, and it will be buoyed up by the difference of the forces.

F. Bodies of this kind, then, will sink in water, till so much of them is below the surface, that a bulk of water, equal to the bulk of the part of the body below the surface, is of a weight equal to the weight of the whole body.

E. Will you explain this more particularly?

F. Suppose the body to be a piece of wood, part of which will be above, and part below the surface of the water: in this state conceive the wood to be frozen into the water.

C. I understand you; if the wood be taken out of the ice, a vacuity will be left, and the quantity of water that is required to fill that vacuity will weigh as much as the whole substance of the wood.

F. That was what I meant to have said.

There is one case remaining: where equal bulks of the water and the wood are of the same weight, the force with which the wood endeavours to descend, and the force that opposes it, being equal to one another, and acting in contrary directions, the body will rest between them, so as neither to sink by its own weight, nor to ascend by the upward pressure of the water.

Fig. 17.

E. What is the meaning of this glass jar with the images in it?

F. I placed it on the table in order to illustrate our subject to-day. You observe that, by pressing the bladder with my hand, the three images all sink.

E. But not at the same moment.

F. The images are made of glass, and of about the same specific gravity with the water surrounding them, or perhaps rather less than it, and consequently they all float near the surface. They are hollow, with little holes in the feet. When the air, which lies between the bladder and the surface of the water, is pressed by my hand, there is a pressure on the water which is communicated through it, and that part of it which lies contiguous to the feet of the images will be forced into their bodies, by which their weight is so much increased as to render them heavier than the water, and they descend.

C. Why do they not all descend to the same depths?

F. Because the hollow part of the image B is larger than the

hollow part of D, and that is larger than that of C; consequently the same pressure will force more water into E than into D, and more into D than into C.

E. Why do they begin to ascend now you have taken your hand away?

F. I said the hollow parts of the images were empty, which was not quite correct: they were full of air, which, as it could not escape, was compressed into a smaller space when the water was forced in by the pressure upon the bladder. But as soon as the pressure is removed, the air in the images expands, drives out the water, and they become as light as at first, and will therefore rise to the surface.

C. The images, in rising up to the surface, turned round.

F. This circular motion is owing to the hole being on one side; and when the pressure is taken off, the water issuing out quickly is resisted by the water in the vessel, and the reaction being exerted on one foot, turns the figure round.

CONVERSATION XII.

Of the Methods of finding the Specific Gravity of Bodies.

E. What are you going to weigh with these scales?

F. This instrument is called the hydrostatical balance; it differs but little from the balance in common use. Some instruments of this kind are more complicated, but the most simple are best adapted to my purpose.

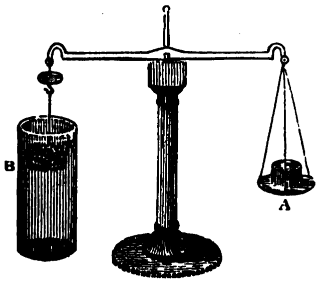


Fig. 18.

To the beam two scale-pans are adjusted, which may be taken off at pleasure. There is also another pan of equal weight with one of the others, furnished with shorter strings and a small hook, so that any body may be hung to it, and then immersed in the vessel of water B.

C. Is it by means of this instrument that you find the specific gravity of different bodies?

F. It is: I will first give you the rule, and then illustrate it by experiments. The rule should be committed to memory.

"Weigh the body first in air, that is, in the common method; then weigh it in water; observe how much weight it loses by being weighed in water; and, by dividing the former weight by the loss sustained, the result is its specific gravity, compared with that of the water."

I will give you an example. I take a Queen Victoria sovereign from my purse: it happens to be a little worn; but never mind, it will do. I suspend it by a hair to the hook at the bottom of the pan, and find it weighs $122\frac{3}{4}$ grs. We will now place a tumbler beneath, so that it hangs withinside the tumbler, and carefully pour in water, till it is submerged. I now find it lighter, and must remove 7 grains to make it balance; it weighs only $115\frac{3}{4}$ grs.

C. Then if I divide $122\frac{3}{4}$ by 7, I have a little more than $17\frac{1}{2}$ for the specific gravity.

E. Then that sovereign is about $17\frac{1}{2}$ times heavier than water.

F. Had our sovereign been new, it would have weighed 123·274 grs., or a little more than $123\frac{1}{4}$; and had we weighed to tenths instead of to quarters of a grain, we should have found it had lost 7·18 grs., and that its specific gravity was 17·157, or nearly $17\frac{1}{6}$.

E. I do not understand the reason of all this.

F. In this scale is a basin filled accurately to the brim with water. I will put a piece of mahogany into it very gently; anything else would answer the same purpose.

E. The water runs over into the scale.

F. So I expected it would: now everything is at rest, and the basin is just as full as it was at first, only that the wood and water together fill the basin, whereas it was all water before. I will take away the basin, and put the mahogany by itself into the other scale.

E. It balances the water that ran out of the basin.

C. The mahogany then displaced a quantity of water equal to itself in weight.

F. And so did the sovereign just now; and if you had taken the same precaution, you would have found that the quantity of water, equal in bulk to the sovereign, weighed 7 grains, the weight which it lost by being weighed in the fluid.

E. Am I to understand, that what any substance loses of its weight, by being immersed in water, is equal to the weight of a quantity of water of the same bulk as the substance itself?

F. This is true, if the body be wholly immersed in water; and with regard to all substances that are specifically heavier than water, you may take it as an axiom, that "every body,

when immersed in water, loses as much of its weight as is equal to the weight of a bulk of water of the same magnitude."

I will now place this empty box in the basin filled to the edge with water, and, as before, it drives over a quantity of the fluid equal in weight to itself. Put in two penny-pieces, and you perceive the box sinks deeper into the water.

C. And they drive more water over: as much, I suppose, as is equal in weight to the copper coin.

F. Right: how long could you go on loading the box?

C. Till the weight of the copper and box, taken together, is something greater than the weight of as much water as is equal in bulk to the box.

F. You understand, then, the reason why boats, barges, and other vessels, swim on water; and to what extent you may load them with safety.

E. They will swim so long as the weight of the vessel and its lading together is less than that of a quantity of water equal in bulk to the vessel.

F. Can you, Charles, devise any method to make iron or lead swim, which are so much heavier than water?

C. I think I can. If the metal be beat out very thin, and the edges turned up, I can easily conceive that a box or a boat of it may be made to swim.

E. I have often wondered how the ball in the cistern acts.

F. The ball, though made of copper, which is eight or nine times heavier than water, is beat out so thin, that its bulk is much lighter than an equal bulk of water. By means of a handle it is fastened to the cock, through which the water flows, and as it sinks or rises, it opens or shuts the cock.

If the cistern is empty, the ball hangs down and the cock is open, to admit the water freely. As the water rises in the cistern it reaches the ball, which, being lighter than the water, rises with it, and, by rising gradually, shuts the cock, and, if it be properly placed, it is contrived to shut the cock just at the moment that the cistern is full.

In the same way that these balls are made, boats of iron are now constructed. They will last longer than wood, and cause less friction in passing through the water.

Iron vessels are very frequently constructed now; many small ones are well known on the Thames; some of a larger class voyage from Folkstone and Dover to Boulogne and Calais respectively; but the largest that has been constructed is the Great Britain steam-ship, which has more than once made the voyage to America.

Can you, Emma, find the specific gravity of this piece of silver?

E. It weighs in air 318 grains. I now fasten it to the hook with the horsehair, and it weighs in water 288 grains, which, taken from 318, leave 30, the weight it lost in water. By dividing 318 by 30, the quotient is about 10½; consequently, the specific gravity of the silver is ten and a half times greater than that of water.

F. What is the specific gravity of this piece of flint-glass? It weighs 12 pennyweights in air.

C. And in water it weighs only 8, and consequently loses 4 by immersion; and 12 divided by 4 gives 3; therefore, the specific gravity of flint-glass is 3 times greater than that of water.

F. This is not the case with all flint-glass; it varies from 2 to almost 4.

Fig. 19.

Here is an ounce of quicksilver; let me know its specific gravity by the method now proposed.

E. How will you manage that? you cannot hang it upon the balance.

F. But you may suspend this glass bucket on this hook; immerse it in the water, and then balance it exactly with weights in the opposite scale.

I will now put into the bucket the ounce or 480 grains of quicksilver, and see how much it loses in water.

C. It weighs 445 grains, and consequently it lost 35 grains by immersion; and 480 divided by 35 give almost 14, so that mercury is nearly 14 times heavier than water.

F. In the same manner we obtain the specific gravity of all bodies that consist of small fragments. They must be put into the glass bucket and weighed; and then, if from the weight of the bucket and body in the fluid you subtract the weight of the bucket, there remains the weight of the body in the fluid.

E. Why do you make use of horsehair to suspend the substances with? would not silk or thread do as well?

F. Horsehair is by much the best, for it is very nearly of the same specific gravity as water; and its substance is of such a nature as not to imbibe moisture.

CONVERSATION XIII.

Of the Methods of finding the Specific Gravities of Bodies.

C. How am I to find out the specific gravity of this piece of beech-wood? it will not sink in the water.

F. A little consideration will show you how to contrive means to sink the beech, by joining a piece of lead or other metal to it, for instance. It weighs 660 grains; I will annex to it an ounce or 480 grains of tin, which I know in water loses of its weight 51 grains. In air, therefore, the weight of the wood and metal taken together is 1140 grains; but in water you see they weigh but 138 grains: 138 taken from 1140 leave 1002, the difference between the weights in air and in water.

C. I now see the mode of finding what I want. The whole mass loses 1002 grains by immersion, and the tin by itself lost in water 51 grains; therefore the wood lost 951 grains of its weight by immersion; and 660 grains, the weight of the beech in air, divided by 951, which it may be said to lose by immersion, leaves in decimals for a quotient ·694.

F. Then making water, the standard, equal to 1, the beech is ·694, or nearly $\frac{7}{10}$ths of 1; that is, the specific gravity of a cubic foot of water is to that of a cubic foot of beech as 1000 to 694; for the one weighs 1000 ounces, and the other 694 ounces.

E. It seems odd how a piece of wood that weighs about 660 grains in air, should lose of its weight 951 grains.

F. You must, in this case, consider the weight necessary to make it sink in water, which must be added to the weight of the wood.

I will now endeavour to make the subject easier by a different method.

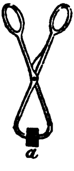


Fig. 20.

This small piece of elm *a*, I will place between the tongs, that are nicely balanced on the beam. The elm weighs 36 grains. To detain it under water I must hang 24 grains to the end of the lever on which the tongs are fixed; then, by the Rule of Three, I say, as the specific gravity of the elm is to the specific gravity of the water, so is 36, the weight of the elm, to 60, the weight of the elm and the additional weight required to sink it in water, or as 60 : 36, so is the specific gravity of the water to the specific gravity of the elm.

E. You have not obtained the specific gravity of the elm, but a proportion only.

C. But three terms are given, because the water is always

considered as unity or 1, therefore the specific gravity of the elm is $\frac{36 \times 1}{60} = \cdot 6$

E. I do not yet comprehend the reason of the proportion assumed.

F. It is very simple. The elm is lighter than the water, but by hanging weights to the side of the balance, to which it is attached, in order to detain it just under water, I make the whole exactly equal to the specific gravity of the water; by this means it is evident, that the comparative gravity of the elm is to that of the water as 36 to 60.

Try this piece of cork in the same manner.

E. It weighs ½ an ounce, or 240 grains, in air; and to detain the cork and tongs just under water, I am obliged to hang 2 ounces, or 960 grains, of lead on the lever; therefore the specific gravity of the cork is to that of the water as 240 is to 1200; and 240 divided by 1200 gives the decimal ·2.

F. Then the specific gravity of water is 5 times greater than that of cork.

C. We have accordingly obtained the specific gravities of water, beech, elm, and cork, which are as 1, ·7 nearly, ·6, and ·2.

F. You now understand the methods of obtaining the specific gravity of all solids, whether lighter or heavier than water. In making experiments upon light and porous woods, the operations must be performed as quickly as possible, to prevent the water from getting into the pores.

C. And you have likewise shown us a method of getting the specific gravities of fluids, by weighing certain quantities of each.

F. I have a still better method; the rule I will give in words: you shall illustrate it by examples.

"If the same body be weighed in different fluids, the specific gravity of the fluids will be as the weights lost."

E. The body made use of must be heavier than the fluids.

F. Certainly: this glass ball loses of its weight, by immersion in water, 803 grains; in milk it loses 831 grains; therefore the specific gravity of water is to that of milk as 803 to 831. Now a cubical foot of water weighs 1000 ounces: what will be the weight of the same quantity of milk?

E. As $803 : 831 :: 1000 : \frac{1000 \times 831}{803} = 1035$ ounces nearly.

F. Do you, Charles, tell me what is the specific gravity of some spirits of wine which I have in this phial.

C. The glass loses in water 803 grains, in the spirits of wine it loses 699 grains, therefore the specific gravity of water is to

the spirit as 803 is to 699; and to find the weight of a cubical foot of the spirit, I say, as

$$803 : 699 :: 1000 : \frac{1000 \times 699}{803} = 870 \text{ ounces.}$$

There is another very elegant method. A very thin glass bottle is prepared, and into it is poured exactly 1000 grains of distilled water, and the height it reaches is marked on the neck; a piece of lead is made to counterpoise the bottle, when thus filled. If the bottle is now filled up to the mark with any other liquid heavier than water, the number of extra grains added to 1000 gives the specific gravity of the liquid; for instance, if sulphuric acid were weighed, it would require 845 additional grains, so that its specific gravity would be 1845. For lighter liquids, as alcohol, &c., the weights must be put in with the bottle, and subtracted from a thousand. If alcohol were weighed, about 200 grains must be added, which will make its specific gravity 800.

F. You may now deduce the method of comparing the specific gravities of solids one with another without making a common standard.

Here is an ounce of lead and another of tin: I may weigh them in any fluid whatever: in water the lead loses by immersion 42 grains, and the tin 63 grains.

E. Is the specific gravity of the lead to that of the tin as 42 to 63?

F. No: "the specific gravities of bodies are to one another *inversely* as the losses of weight sustained:" therefore the specific gravity of the lead is to that of the tin as 63 to 42; or, if a block of lead weighs 63 pounds, the same sized block of tin will weigh 42 pounds only.

C. I think I see the reason of this: the heavier the body, the less in proportion it loses of its weight by immersion; therefore, of two bodies whose absolute weights are the same, that is, each weighing an ounce, pound, &c., the one which loses least of its weight will be specifically the heaviest.

F. You are right; for the specific gravity of bodies is as their density, and their densities are inversely as the weights they lose by immersion; that is, the body which is most dense will lose the least in water.

E. Why does the more dense body lose less of its weight when immersed in water?

F. Because it displaces the least quantity of water: thus an ounce of copper would occupy seven or eight times less space than an ounce of wood; and would, of course, displace seven or eight times less water.

CONVERSATION XIV.

Of the Methods of obtaining the Specific Gravity of Bodies.

E. To whom are we indebted for the discovery of the mode of performing these operations?

F. To that most celebrated mathematician of antiquity, Archimedes.

C. Was he not slain by a common soldier at the siege of Syracuse?

F. He was, to the great grief of Marcellus, the Roman commander, who had ordered that his house and person should be respected; but, as Livy says, he was slain by a soldier, not knowing who he was, while he was describing mathematical diagrams on the ground; that the Roman commander gave him a magnificent funeral, and made his name a protection and honour to those who could claim a relationship to him. The death of Archimedes happened more than 200 years before the birth of Christ. His celebrity was so great among the literati of Rome, that his tragical end caused more real sorrow than the capture of the whole island of Sicily did joy.

We are informed by history, that it was by the wisdom of Archimedes that the fate of Syracuse was long suspended: by his inventions, multitudes of the Roman army were killed, and their ships destroyed; and it is added, that he made use of burning glasses, which, at the distance of some hundreds of yards, set the Roman vessels on fire.

But to return to our subject. To Archimedes, the world is indebted for the discovery, "That every body heavier than its bulk of water loses so much of its weight by being suspended in water, as is equal to the weight of a quantity of water equal to its bulk."

E. How did he make the discovery?

F. Hiero, king of Syracuse, had given to a jeweller a certain quantity of pure gold, to make a crown for him. The monarch, when he saw the crown, suspected the artist of having kept back part of the gold.

E. Why did he not weigh it?

F. He did, and found the weight right: but he suspected perhaps from the colour of the crown, that some baser metal had been mixed with the gold, and therefore, though he had his weight, yet only a part of it was gold, the rest was silver or copper. He applied to Archimedes to investigate the fraud.

C. Did he melt the crown, and endeavour to separate the metals?

F. That would not have answered Hiero's intentions: his object was to detect the roguery, if any, without destroying the workmanship. While the philosopher was intent upon the problem, he went, according to his custom, into the bath, and he observed that a quantity of water flowed over, which he thought must be equal to the bulk of his own body. He instantly saw the solution of Hiero's problem. In raptures at the discovery he is said to have leaped from the water, and run naked through the streets of the city, shouting aloud Ἑυρηκα! Ἑυρηκα! "I have found it out! I have found it out!"

When the excess of his joy was abated, he took two masses, one of gold, and the other of silver, each equal in weight to the crown, and having filled a vessel very accurately with water, into which he first dipped the silver mass, and observed the quantity of water that flowed over, he then did the same with the gold, and found that a less quantity of water had flowed over than before.

C. And he was, from these trials, led to conclude, that the bulk of the silver was greater than that of the gold?

F. He was; and also that the bulk of water displaced was, in each experiment, equal to the bulk of the metal. He then made the same trial with the crown, and found that though of the same weight with the masses of silver and gold, yet it displaced more water than the gold, and less than the silver.

E. Accordingly he concluded, I imagine, that it was neither pure gold nor pure silver.

C. But how could he discover the proportions of each metal?

F. I believe we have no other facts to carry us farther into the history of this interesting experiment. But to-morrow I will endeavour to explain and illustrate the matter.

CONVERSATION XV.

On the Method of obtaining the Specific Gravity of Bodies.— Table of Specific Gravities.

F. Before we commence conversation on the subject of alloys which I promised to take up this evening, I must not omit to tell you that metals are rarely mixed or alloyed without the compounds taking to themselves a new specific gravity, differing from that which would have been deduced by calculation from the relative proportions of each metal. For instance, the alloys of gold with *zinc*, *tin*, *bismuth*, or *antimony*, have a greater specific gravity than the mean of the metals forming the alloy; the alloys of *gold* with *silver*, *iron*, *lead*, or *copper*, have a less spe-

cific gravity than would be given by calculation. As an example, the true specific gravity of standard gold, which contains 11 parts gold and 1 part copper, is 17·157; its calculated specific gravity is 17·68.

C. If you are good enough to tell me how you calculate the specific gravity of the alloy called standard gold, I shall be able to calculate other mixtures and alloys.

F. Let the mass of standard gold consist of 1200 grains, of which 1100 will be gold and 100 copper. Divide the 1100 grains of gold by 19·26, which is the specific gravity of cast gold, and you obtain 57·11 grains, lost by the gold in water. Divide the 100 grains of copper by 8·85, the specific gravity of cast copper, and you obtain 11·29 grains, lost by the copper in water.

C. I can now go on. I add the two losses together, and obtain 68·4 grains lost by the gold and copper together. And as they weigh in all 1200 grains, I divide this by 68·4, and obtain 17·68, the specific gravity you have given us.

F. Bearing in mind, therefore, the facts, that alloys have a density either greater or less than would accurately represent the proportions of the constituent metals, you will understand that, although the specific gravity will give a very close approximation to the amount of inferior metal, mixed with gold or silver in base coin, yet it will not give you a philosophically true result.

C. Since we last met, I have weighed the bad sovereign that mamma took in change last winter, and find it loses 8 grains in water. Presuming it to be adulterated with silver, as our tutor suspects, how am I to discover how much silver is there in place of gold? It weighs in air 123·274 grains.

F. The rule is this:—"Find what a good sovereign would lose in water; find what an equal weight of silver would lose in water; subtract the former from the grains lost by the base sovereign, which will give the ratio or proportion of the *silver*; subtract the loss of the base coin from the loss of the silver mass, which gives the ratio or proportion of *gold*."

C. In our last conversation, we found that a good sovereign lost 7·18 grains. I have already said the base coin lost 8 grains; and I can easily find the loss of a silver sovereign weighing 123·274 grains, if you will be good enough to tell me the specific gravity of silver.

F. I have here a table of specific gravities, in which you will find 10·3 the specific gravity of standard silver.

C. I find that 123·274, divided by 10·3, is 11·96 grains, the loss in water of the silver.

F. I will put these figures before you in order, showing the subtraction required: —

Loss in water of the base sovereign -	8	
„ „ good „ -	7·18	
Difference = proportion of silver -		·82
Loss in water of a mass of silver - -	11·96	
„ „ base sovereign - -	8	
Difference = proportion of gold -		3·96
Sum of ratios - -		4·78

J. But this gives us only the ratio or proportion of silver and gold, but not the actual quantity.

F. A very simple rule of proportion will give it. As the sum of the ratios is to either the silver or the gold ratio, so is the total weight of the coin to the proportion of silver or gold.

C. I have it: —

As 4·78 : ·82 :: 123·274 : 21·14gr.

The sovereign, therefore, contains 21⅐ grains of silver.

F. A shilling weighs 87·272 grains, so that the silver used for adulteration is worth about 3*d.*; but as a good sovereign is worth 240*d.*, the gold is worth about 2*d.* per grain, which gives 42*d.* as the value of the gold that has been abstracted: the difference is 39*d.*, or 3*s.* 3*d.* So that your mamma's sovereign is only worth 16*s.* 9*d.* Now suppose the sovereign had been adulterated with copper, can you tell me, Charles, what it would have been worth?

C. By dividing 123·274 grains by 8·85, the specific gravity of copper, I obtain 13·92 grains. I will now imitate your calculation, using copper for silver:

Loss in water of base sovereign - -	8	
„ „ good „ - -	7·18	
Difference = proportion of copper -		·82
Loss in water of mass of copper -	13·92	
„ „ base sovereign - -	8	
		5·92
Sum of the ratios - - -		6·74

I then take the proportion: —

As 6·74 : ·82 :: 123·274 : 14·9 grs.

So that about 15 grains of copper are in place of gold; the sovereign, therefore, is worth 2*s.* 6*d.* less, or 17*s.* 6*d.*

F. You are right.

The following tables show the specific gravities of various bodies, water being taken as 1.

Liquids.

Sulphuric ether	·715	Sea Water	1·026
Absolute alcohol	·792	Nitric acid of commerce	1·220
Naphtha	·847	Sulphuret of carbon	1·263
Essence of turpentine	·869	Sulphuric acid, concentrated	1·841
Olive oil	·915	Mercury	13·596
Bordeaux wine	·994		
Distilled Water	1·000		

Woods.

Lignum vitæ	1·330	Elm	·800
Heart of oak	1·170	Yellow fir	·657
Box	·910	Lime	·604
Beech	·852	Cedar	·561
Ash	·845	Poplar	·383
Yew	·807	Cork	·240

Metals.

Antimony	6·720	Standard silver (11·1 silver + ·9 copper)	10·300
Zinc	7·190	Cast silver	10·470
Cast-iron	7·200	Lead	11·350
Tin	7·291	Mercury	13·596
Iron	7·788	Standard gold (11 gold + 1 copper)	17·157
Steel	7·810	Cast gold	19·260
Manganese	8·010	Forged gold	19·360
Cast copper	8·850	Platinum	21·530
Rolled copper	8·950	Rolled platinum	22·060
Bismuth	9·822		

Sundries.

Pine charcoal	·333	Sèvres porcelain	2·310
Oak "	·421	China porcelain	2·380
Walnut "	·625	Graphite	2·500
Ice	·865	Flint	2·600
Amber	1·080	Granite	2·050
Coal	1·250	Coral	2·680
Alum	1·700	Alabaster	2·700
Saltpetre	1·930	Emerald	2·700
Sulphur	2·085	Marble	2·720
Salt	2·100	Iceland spar	2·723

SUNDRIES — *continued.*

Pearls	2·750	Topaz	3·500
Granite (dense)	2·750	Diamond	3·500
Jasper	2·800	Diamond (dense)	3·530
Slate	2·810	Sapphire	3·990
Slate (dense)	2·850	Garnet (dense)	4·240
Lime	3·150	Ruby	4·280
Flint-glass	3·330	White lead	6·300
Garnet	3·350	Brass	8·300
Malachite	3·500	Bronze	8·950

GASES, AIR BEING TAKEN AS 1.

Hydrogen	·069	Oxygen	1·106
Carburetted hydrogen	·555	Carbonic acid	1·529
Air	1·000		

E. There is a silver cream-jug in the parlour; I have heard mamma say, she did not think it was real silver: how could she find out whether she has been imposed on?

F. Go and fetch it. We will now weigh it.

E. It weighs $5\frac{1}{2}$ ounces; but I must weigh it in water, and it has lost in the water $10\frac{1}{4}$ pennyweights; and dividing $5\frac{1}{2}$ ounces, or 110 pennyweights, by $10\frac{1}{4}$, I get for answer 10·7, the specific gravity of the jug.

F. Then there is no cause for complaint, for the specific gravity of good wrought silver is seldom more than this.

CONVERSATION XVI.

Of the Hydrometer.

F. Before I describe the construction and uses of the hydrometer, I will show you an experiment or two. You know that wine is specifically lighter than water, and the lighter body will always be uppermost. I have filled the bulb B with port wine to the top of the narrow stem *x*. I now fill A with water.

Fig. 21.

E. The wine is gradually ascending like a fine red thread through the water to its surface.

F. And so it will continue till the water and wine have changed places.

C. I wonder the two liquids do not mix, as wine and water do in a common drinking glass.

F. It is the narrowness of the stem *x* which prevents the admixture: in time, however, this would be effected, because water and wine have what the chemists call an attraction for each other.

B

Fig. 22.

Here is a small bottle B, with a neck three inches long, and about one sixth of an inch wide; it is full of red wine. I will now place it at the bottom of a jar of water, a few inches deeper than the bottle is high. The wine, you observe, is ascending through the water.

E. This is a very pretty experiment: the wine rises in a small column to the surface of the water, spreading itself over it like a cloud.

F. Now reverse the experiment: fill the bottle with water, and plunge its neck quickly into a glass of wine with its mouth downwards; the wine is taking the place of the water.

C. Could you decant a bottle of wine in this way without turning it up.

F. I could, if the neck of the decanter were sufficiently small. The negroes in the West Indies are said to be well acquainted with this part of hydrostatics, and to plunder their masters of rum by filling a common bottle with water, and plunging the neck of it into the bung-hole of the hogshead.

Upon the principle of lighter fluids keeping the uppermost parts of a vessel, several fluids may be placed one upon another in the same vessel without mixing; thus in a long upright jar, three or four inches in diameter, I can place water first, then port wine, then oil, brandy, oil of turpentine, and alcohol.

C. How would you pour them in one upon another without mixing?

F. This will require a little dexterity; when the water is in, I lay a piece of very thin pasteboard over its surface, and then pour in the wine; after which I take away the pasteboard, and proceed in the same manner with the rest.

Take a common goblet or drinking-glass, pour water in, and then lay a thin piece of toasted bread upon the water, and you may pour your wine upon the bread, and the two fluids will remain for some time separate.

E. Is the toast placed merely to receive the shock of the wine when poured in?

F. That is the reason. I will now proceed to explain the principle of the *hydrometer*, an instrument contrived to ascertain with accuracy and expedition the specific gravities of different fluids.

A B is a hollow cylindrical tube of glass, ivory, copper, &c., five or six inches long, annexed to a hollow sphere of copper D: to the bottom of this is united a smaller sphere E, containing a little quicksilver, or a few shot sufficient to poise the machine, and make it sink vertically in the fluid.

C. What are the marks on the tube?

F. They are degrees, exhibiting the magnitudes of the part below the surface, consequently, the specific gravity of the fluid in which it descends. If the hydrometer, when placed in water, sinks to the figure 10, and in spirits of wine to 11·1, then the specific gravity of the water is to that of the spirit, as 11·1 to 10; for if the same body float upon different fluids, the specific gravity of these fluids will be to each other *inversely* as the parts of the body immersed.

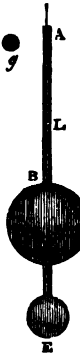


Fig. 23.

E. By *inversely*, do you mean that the fluid in which the hydrometer sinks the deepest is of the least specific gravity?

F. Yes, I do: here is a piece of dry oak, which, if I put into spirits of wine, is entirely immersed: in water the greatest part of it sinks below the surface; but in mercury it scarcely sinks at all. Hence it is evident that the hydrometer will sink deepest in the fluid that is of the least specific gravity.

To render this instrument of more service, a small stem is fixed at the end of the tube, upon which weights, like that at *g*, may be placed. Suppose, then, the weight of the instrument is 10 dwts, and by being placed in any kind of spirit it sinks to a certain point L, it will require an additional weight, suppose 2·6 dwt. to cause it to sink to the same depth in water: in this case the specific gravity of the water to the spirit will be as 12·6 to 10. By the addition of different weights the specific gravity of any kind of liquor is easily found. The point L should be so placed as to mark the exact depth to which the instrument will sink in the liquor that has the least specific gravity.

C. But you always make the specific gravity of water 1, for the sake of a standard.

F. Right; and to find the specific gravity of the spirit compared with water at 1, I say, as 12·6 : 1 :: 10 : ·791 nearly, so that I should put the specific gravity of this spirit down at ·791 in a table where water was marked 1; and as a cubic foot of water weighs 1000 ounces, a cubic foot of this spirit would weigh 791 ounces, which is generally the standard of *absolute alcohol.*

E. Is this what is usually called spirits of wine?

F. No; it is the alcohol of the chemists, one pint of which, added to a pint of water, makes a quart *nearly* of common spirits of wine.

C. You said 791 was *generally* the specific gravity of alcohol: what causes the difference at other times?

F. It is not always manufactured of equal strength; and the same fluids vary in respect to their specific gravity by the different degrees of heat and cold in the atmosphere. The cold of winter condenses the fluid, and increases the specific gravity; the heat of summer causes an expansion of the fluid, and a diminution of its specific gravity.

E. You said just now that a pint of water added to a pint of alcohol, made *nearly* a quart of spirits of wine; surely two pints make a *full* quart?

F. Indeed they will not. A pint of water added to a pint of water will make a quart; and a pint of spirit added to a pint of spirit will make a quart; but mix a pint of spirit with a pint of water, and there is a certain chemical union or penetration between the particles of the two fluids, so that they will not make a quart.

CONVERSATION XVII.

Of the Hydrometer, and Swimming.

C. To what purposes is the hydrometer applied?

F. It is used in breweries and distilleries, to ascertain the strength of their different liquors; and by this instrument the excise officers gauge spirits, and thereby determine the duties to be paid to the revenue.

I think from the time we have spent in considering the specific gravity of different bodies, you will be at no loss to account for a variety of circumstances that may present themselves to your attention in the common concerns in life. Can you, Emma, explain the theory of floating vessels?

E. All bodies that float on the surface of the water displace as much fluid as is equal in weight to the weight of the bodies: therefore, in order that a vessel may keep above water, it is only necessary to take care that the vessel and its cargo, passengers, &c., should be of less weight than the weight of a quantity of water equal in bulk to that part of the vessel which it will be safe to immerge in the water.

F. Salt water,—that is, the water in the sea,—is specifically heavier than fresh or river water.

C. Then the vessel will not sink so deep at sea as it does in the Thames.

F. That is true; if a ship is laden at Sunderland, or any other sea-port, with as much coals or corn as it can carry, it may sail

very safely till it reach the fresh water in the Thames; but there it will infallibly go to the bottom unless some of the cargo be taken out.

E. How much heavier is sea water than the fresh?

F. About one fortieth part, which would be a guide to the master of a vessel, who was bent upon freighting it as deeply as possible.

C. In bathing, I have often tried to swim, but have not yet been able to accomplish the task; is my body specifically heavier than the water?

F. I hope you will learn to swim, and well, too; it may be the means of saving your own life, and rescuing others who are in danger of drowning.

By some very accurate experiments made by Mr. Robertson, a late librarian of the Royal Society, upon ten different persons, the mean specific gravity of the human body was found to be about one ninth less than that of common river water.

C. Why then do I sink to the bottom? I ought to swim like wood on the surface.

F. Though you are specifically lighter than water, yet it will require some skill to throw yourself into such a position as to cause you to float like wood.

C. What is that position?

F. Dr. Franklin recommends a person to throw himself in a slanting position on his back; but his whole body, except the face, should be kept under water.

Unskilful persons in the act of attempting this are apt to plunge about and struggle; by this means they take water in at their mouths and nostrils, which of itself would soon render them as heavy or heavier than the water. Moreover, the coldness of the stream tends to contract the body; perhaps fear has the same tendency; all these things put together will easily account for a person sinking in the water.

E. But if a dog or a cat be thrown into a pond they seem as terrified as I should be in a like situation; yet they never fail of making their way out by swimming.

F. Of all land animals, man is, probably, the most helpless in this element. The brute creation swim naturally, the human race must acquire the art by practice. In other animals the trunk of the body is large, and their extremities small: in man it is the reverse, the arms and legs are large in proportion to the bulk of the body, but the specific gravity of the extremities is greater than that of the trunk, consequently it will be more difficult for man to keep above water than four-footed animals; besides, the act of swimming seems more natural to them than

to us, as it corresponds more nearly to their mode of walking and running than to ours.

C. I will try the next time I bathe to throw myself on my back according to Dr. Franklin's directions.

F. Do not forget to make your experiments in water that is not so deep as you are high by at least a foot.

It is not so generally known as it ought to be, that the depth of a clear stream of water is always one fourth greater than it appears to be.*

C. If the river appear to be only three feet deep, may I reckon upon its being full four feet?

F. Yes; you must estimate it in this manner. Remember also, that if a person sink slowly in water ever so deep, a small effort will bring him up again, and if he be then able to throw himself on his back, keeping only his face above water, all will be well †; but if, instead of this, he is alarmed, and by struggling throw himself so high above the water, that his body does not displace so much of it as is equal to his weight, he will sink with an accelerated motion: a still stronger effort, which the sense of danger will inspire, may bring him up again, but in two or three efforts of this kind his strength fails, and he sinks to rise no more alive.

E. Is it the upward pressure which brings up a person that is at a considerable depth in the water?

F. It is; this upward pressure balances the weight of water which he sustains, or he would be crushed to pieces by it.

Cork an empty bottle ever so well, and with weights plunge it down a hundred yards into the sea, and the pressure of the water will force the cork into the bottle.

C. I credit that assertion because it is *yours*; and I know that although you may like now and then to *surprise* us, you never intentionally *deceive* us. But I confess that I do not, as yet, see the entire reason of the fact.

F. Have you forgotten, then, that the pressure of water upon any horizontal surface is *as the depth* of the liquid above that surface?

C. No, papa, I have not. But I do not think we have hitherto estimated the pressure at any considerable depths.

F. Suppose, then, you attempt to ascertain the pressure of water upon a square inch placed horizontally at the depth of 30 feet.

* The reason of this deception is explained in our Conversations on Optics.—See Conversation IV., on Optics.

† It has been asserted lately, in some of our best periodical works, that if a person falling in the water have presence of mind to lean his head a little backward, and never lift his hands above the water, he cannot sink.

C. In order to do that I fancy it will be easiest to find the pressure on a square *foot* at the same depth; and that, if I do not mistake, will be equivalent to the weight of a column of water having a base of a square foot, and being 30 feet high.

F. So far you are quite right: go on.

C. This column will contain 30 cubic feet, which will weigh 30 times 1000 ounces, or 30 times $62\frac{1}{2}$ pounds, that is to say, 1875 pounds avoirdupois.

If I divide this by 144, the quotient will measure the pressure upon a *square inch*, at the depth of 30 feet; this comes to 13 pounds and $\frac{1}{48}$. I suppose I may call it 13 pounds.

E. Yes, Charles; that you may, I will warrant. And if I am not mistaken, I see the reason why papa chose *thirty* feet. It was because *thirteen* pounds, the pressure, has the same first syllable as *thirty* feet, the depth; by which means both are more easily recollected. Am I right in this conjecture?

F. You are.

Now let me ask you what would be the pressure upon a square inch at the depth of 300 feet?

E. Ten times 13, or 130 pounds; and it is very probable that pressure would thrust in the cork.

F. What would be the pressure upon a square inch at the depth of 3000 feet?

E. Ten times 130, or 1300 pounds. But that is an enormous pressure: has it ever been tried?

F. Yes, in the northern seas; specimens of different kinds of wood have been tied to cords and sunk to depths of more than 6000 feet.

C. I think I can foresee that wood kept immersed at such great depths would have much water squeezed into its pores. Was that actually the case?

F. Yes. Ash, the specific gravity of which, before immersion, was ·654, after being kept nearly 3 hours at the depth of 6348 feet, became specifically heavier than water, its specific gravity having become 1·168. Fir, by a like process, increased in specific gravity from ·473 to 1·081; oak, from ·720 to 1·185. So that none of the specimens would, after this submersion, swim in water. This result, however, is by no means incredible, when it is considered that the pressure upon each square inch of surface exceeded 25 cwt.

E. We thank you, papa, for drawing our attention to this interesting experiment.

CONVERSATION XVIII.

Of the Syphon.

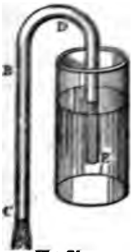


Fig. 24.

F. This bended tube is called a syphon, and it is used to draw off water, wine, or other fluids, from vessels which it would be inconvenient to move from the place in which they stand.

C. I do not see how it can draw liquor out of any vessel — why is one leg longer than the other?

F. I will first show you how the operation is performed, and then endeavour to explain the principle.

I fill the tube E D C with water, and then placing a finger on E, and another on C, I invert the tube, and immerse the shorter leg into a jar of water; and having taken my fingers away, you see the water runs over in a stream.

E. Will it continue to flow over?

F. It will, till the water in the vessel comes as low as E, the edge of the syphon.

C. Is this accounted for by pressure?

F. To the pressure or weight of the atmosphere we are indebted for the action of the syphon, pumps, &c. At present you must take it for granted that the air which we breathe, though invisible, has weight, and that the pressure occasioned by it is equal to about 14 or 15 pounds upon every square inch. The surface of this table is equal to about six square feet, or 864 square inches, and the pressure of the atmosphere upon it is equal to at least 12,000 pounds.

E. How does the pressure of the air cause the water to run through the syphon?

F. The principle of the syphon is this: the two legs are of unequal length; consequently, the weight of water in the longer leg is greater than that in the shorter, and therefore will, by its own gravity, run out at C, leaving a vacuum from D to E, did not the pressure of the atmosphere on the surface of the water in the jar force it up the leg D E, and thus continually supply the place of the water in D C.

C. But since the pressure of fluids acts in all directions, is not the upward pressure of the atmosphere against C, the

mouth of the tube, equal to the downward pressure on the surface of the water?

F. The pressure of the atmosphere may be considered as equal in both cases. But these equal pressures are counteracted by the pressures of the two unequal columns of water, D B and D C. And since the atmospheric pressure is more than sufficient to balance both these columns of fluid, that which acts with the lesser force, that is, the column D B, will be more pressed against D C than D C is against D B at the vertex D; consequently the column D B will yield to the greater pressure, and flow off through the orifice C.

E. Would the same thing happen if the outer leg D C were shorter than the other?

F. If D C were broken off at B, even with the surface of the water, no water would run over; or if it were broken off anywhere lower than B, it would only run away till the surface of the fluid descended to a level with the length of the outer tube, because then the column D B will be no more pressed against D C than D C is against D B, and consequently the syphon will empty itself; the water in the outer leg will run out at the lower orifice, and that in the inner will fall back into the jar.

C. In decanting a pipe of wine, are you obliged first to fill the syphon with liquor, and then invert it?

F. No; a small pipe is fixed to the outer leg of the syphon, by which the air is drawn out of it by the mouth, and the short leg being immersed in the wine, the fluid will follow the air, and run out till the pipe is empty.

The syphon is sometimes disguised for the sake of amusing young people. Tantalus's cup is of this kind. The longer leg of the syphon passes through, and is cemented into the bottom of the cup; if water be poured into the cup, so as not to stand so high as the bend of the tube, the water will remain as in any common vessel; but if it be raised over the bended part of the syphon, it will run over, and continue to run till the vessel is emptied. Sometimes a little figure of a man representing Tantalus conceals the syphon, so that Tantalus, as in the fable, stands up to his chin in water, but is never able to quench his thirst; for just as it comes to a level with his chin, it runs out through the concealed syphon.

Fig. 25.

This is another kind of Tantalus's cup, but the syphon is

Fig. 26.

concealed in the handle, and when the water in the cup, which communicates with the shorter leg at I, is raised above the bend of the handle, it runs out through the longer leg at P, and so continues till the cup is empty. This cup is often made to deceive the unwary, who, by taking it up to drink, cause the water, which was, while at rest, below the bend of the syphon, to run over, and then there is no means of stopping the stream till the vessel is empty.

C. I have frequently seen at the doors of public-houses the contents of hogsheads of spirits drawn off by means of an instrument like a syphon.

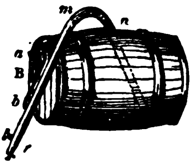


Fig. 27.

F. That is called a distiller's crane or syphon. B represents one of these barrels with the syphon at work from the bung-hole *n*. The longer leg *m r* is about three feet long, with a stop-cock near the middle, which must be shut, and then the shorter leg is immersed in the liquor.

E. Is the air in the short leg forced into the other by the upward pressure of the fluid?

F. It is, and the cock being shut, it cannot escape, but will be very much condensed. If then the cock be suddenly opened the condensed air will rush out, and the pressure of the air on the liquor in the vessel will force it over the bend of the syphon, and cause it to flow off in a stream, as the figure represents. If, however, the barrel be not full, or nearly full, then it is necessary to draw the air out of the syphon by means of a small tube *a b*, fixed to it.

By the principle of the syphon we are enabled to explain the nature of intermitting springs.

E. What are these?

F. They are springs, or rather streams, that flow periodically. A diagram will give a clearer idea of the subject than many words without; G F C represents a cavity in the bowels of a hill from the bottom of which, C, proceeds the irregular cavity C E D, forming a sort of natural syphon. Now, as this fills, by means of rain or snow draining through the pores of the ground, the water will gradually rise in the leg C E, till it has attained the horizontal level *h h*, when it will begin to flow through the leg E D, and continue to increase in the quantity discharged as the water rises higher, till a full stream is sent forth; and then, by

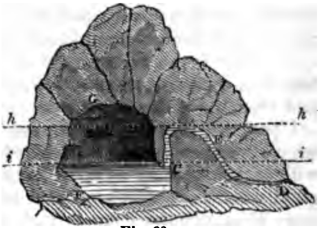


Fig. 28.

the principle of the syphon, it must continue to flow till the water sinks to the level *i i*, when the air will rush into the syphon and stop its motion.

C. And being once brought so low, it cannot run over again till the cavity is full of water, or at least up to the level *h h*, which, as it is only supplied by the draining of the water through the ground, must take a considerable length of time. Is that the reason why they are called intermitting springs?

F. It is: Mr. Clare, in his treatise "On the Motion of Fluids," illustrates this subject by referring to a pond at Gravesend, out of which the water *ebbs* all the time the tide is coming into the adjacent river, and runs in while the tide is going out. Another instance mentioned by the same author is a spring in Derbyshire called the Wedding Well, which, at certain seasons, sends forth a strong stream, with a singing noise, for about three minutes, and then stops again. At Lambourn, in Berkshire, there is a brook which in summer carries down a stream of water sufficient to turn a mill; but during the winter there is scarcely any current at all.

In intermitting springs the periodical returns of the flowing and cessation will be regular, if the filling of the reservoir be so; but the interval of the returns must depend on the quantity of water furnished by the springs.

Many springs are derived from natural syphons, existing in the sides of mountains, &c., at various depths, and to various extents. Some, situated on the tops of hills near to larger ones, supply water all the year, others only periodically, when they usually flow in profusion.

CONVERSATION XIX.

Of the Diving-Bell.

F. Take this ale-glass, and thrust it with the mouth downwards into a glass jar of water, and you will perceive that but very little water will enter it.

C. The water does not rise in it more than about a quarter of an inch: if I properly understand the subject, the air, which filled the glass before it was put in water, is now compressed

into the smaller space; and it is this body of air that prevents more water from getting into the glass.

F. That is the reason: for if you slope the glass a little on one side, a part of the air will escape in the form of a bubble, and then the water will rise higher in the glass.

Upon this simple principle machines have been invented, by which people are able to walk about at the bottom of the sea with as much safety as upon the surface of the earth. The original machine of this kind was much improved by Dr. Halley, more than a century ago; it is called the Diving Bell.

C. Was it made in the shape of a bell?

Fig. 29.

F. It was; and, as great strength was required to resist the pressure of the water, he caused it to be made of copper: this is a representation of it. The diameter of the bottom was five feet, that of the top three feet, and it was eight feet high; to make the vessel sink vertically in water, the bottom was loaded with a quantity of leaden balls.

E. It was as large as a good-sized closet; but how did he contrive to get light?

F. Light was let into the bell by means of strong spherical glasses fixed in the top of the machine.

C. How are the divers supplied with air?

F. Barrels, filled with fresh air, were made sufficiently heavy, and sent down, such as that represented by c; from which a leathern pipe communicated with the inside of the bell, and a stop-cock at the upper part of the bell let out the foul air.

E. The little men seem to sit very contentedly under the bell; yet I do not think I should like a journey with them.

C. I descended the other day in the diving-bell at the Polytechnic, and felt a somewhat disagreeable sensation in my ears; but this sensation appeared painful to some who descended, at least so I judged from their observations as they emerged from the bell. What is the cause of this?

F. It arises from the condensation of the air in the bell; which at considerable depths in the sea is very great, and produces a disagreeable pressure upon all parts of the body, but more particularly in the ears, as if quills were thrust into them. This sensation does not last long, for the air pressing through

the pores of the skin, soon becomes as dense within their bodies as without, when the sense of pressure ceases.

E. They might stop their ears with cotton.

F. One of them once thought himself as cunning as you, and for the want of cotton he chewed some paper and stuffed it in his ears: as the bell descended, the paper was forcibly pressed into the cavities, and it was with great difficulty and some danger that it was extracted by a surgeon.

C. But no barrels of air were sent down to us at the Polytechnic.

F. No; but you must have noticed two men pumping while the bell was in the water: they were sending you air by means of a forcing-pump, which is the plan now adopted in preference to the inconvenient one of sending down barrels of air.

C. Are divers able to remain long under water?

F. Yes; when all things are properly arranged, if business require it, they will stay several hours without the smallest difficulty.

E. But how do they get up again?

F. They are generally let down from on board ship, and taking a rope with them, to which is fixed a bell in the vessel, they have only to pull the string, and the people in the ship draw them up.

C. What does the figure E represent?

F. A man detached from the bell, with a kind of inverted basket made of lead, in which is fixed another flexible leathern pipe, to give him fresh air from the bell as often as he may find it necessary. By this method a man may walk to the distance of 80 or 100 yards from the machine.

E. It is to be hoped his comrades will not forget to supply him with air.

F. If his head is a little above that part of the bell to which the pipe communicates, he can, by means of a stopcock, assist himself as often as he requires a new supply; and that man is always best helped who can help himself.

E. We saw a diver thus protected descend into the tank at the Polytechnic; his helmet was supplied with air from the pump; he carried heavy weights to sink himself; but how did he manage to float again, for he did not remove the weights?

F. No; but he had on a waterproof girdle; and, by turning a cock, he connected this with the helmet, and it became inflated with air, and thus he became buoyant.

E. I observed a great bubbling in the tank while the bell or the diver was down. What was this?

F. The pumpers furnished more air than was needed, and it

escaped under the lip of the bell; also, when the bell was at the bottom of the tank the air it contained was compressed by the depth of water; but as the bell rose the air expanded, and became too much for the bell.

C. Has the diving-bell been applied to any very useful purposes?

F. By means of this invention a great number of valuable commodities have been recovered from wrecks of ships, though at great depths in the sea. The bell is perfectly manageable, and may, by a small boat, be conducted from place to place with the greatest ease. You remember the fearful accident that happened to the Royal George ship of the line, which was suddenly sunk with all the crew, of whom few escaped. The sunk wreck, which was long a great source of interruption to the navigation, has been removed by the continual use of the diving-bell.

CONVERSATION XX.

Of the Diving-Bell.

E. Have there been no accidents attending the use of the diving-bell?

F. The diving-bell proved fatal to Mr. Spalding and an assistant, who went down to view the wreck of the Imperial East-Indiaman, near Ireland. They had descended for the third time, when the twisting of some ropes prevented their announcing their wants to their companions in the ship. Mr. Day also perished at Plymouth in a diving-bell of his own construction, in which he was to have continued, for a wager, twelve hours, one hundred feet deep in water.

C. Did these accidents put an end to the experiments?

F. No; but they have led to improvements in the structure and use of the machine. Mr. Smeaton made use of a cast-iron chest (fig. 30.), the weight of which, 50 cwt., was heavy enough to sink itself. It was $4\frac{1}{2}$ feet in height, the same number of feet in length, and 3 feet wide, and of course afforded sufficient room for two men to work under it at a time.

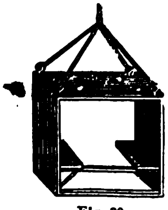


Fig. 30.

E. What are those round things at the top?

F. They are four strong pieces of glass to admit the light. The great advantage which this had above Dr. Halley's bell was, that the divers were supplied with a constant influx of air, without any attention of their own, by

means of a forcing air-pump, worked in a boat upon the water's surface.

C. That is not represented in the plate.

F. Look to fig. 31., which is a diving machine of a different construction, invented by the very ingenious and truly respect. able lecturer, Mr. Adam Walker.*

This machine is of the shape of a conical tub, but little more than one third as large as Mr. Smeaton's. The balls at the bottom are lead, sufficiently heavy to make it sink of itself: a bended metal tube *a b c*, is attached to the outside of a machine with a stopcock *a*, and a flexible leathern tube to the other end *e;* this tube is connected with a forcing air-pump *d*, which abundantly supplies the diver with fresh air. The ropes and leathern tube being flexible, the diver can, with the machine over his head, walk about several yards, in a perpendicular posture; and thus can easily perform any sort of business, nearly as well as on dry land. Mr. Walker says, that the greatest part of the wreck saved from the rich ship Belgioso was taken up by means of his bell. The following anecdote given by this gentleman will entertain my young readers:

Fig. 31.

"As the diver had plenty of air to spare, he thought a candle might be supported in the bell, and he could descend by night. He made the experiment, and presently found himself surrounded by fish, some very large, and many such as he had never seen before. They sported about the bell, and smelt at his legs as they hung in the water: this rather alarmed him, for he was not sure but some of the larger might take a fancy to him; he therefore rang his bell to be taken up, and the fish accompanied him with much good-nature to the surface."

C. I have heard of late of methods that have been adopted of going down tubes to the bottom of rivers without a diving-bell at all; but I could never get a description of the apparatus.

F. You refer to Mr. Cave's modification of the diving-bell. Conceive to yourself a large hemispherical vessel of iron, some

* See Walker's System of Natural Philosophy, 2 vols. 4to.

20 or 30 feet in diameter, and 15 or 20 feet high, with an opening in the centre of the bottom of the vessel. This vessel, with the addition of the air-pump and other necessary apparatus, would of itself constitute a diving-bell.

E. It would be rather a large one, I think; much larger than I had supposed was ever the case.

F. You will find as I go on that this is a fixture, and is only an air-vessel. To the hole in the bottom is fitted a long iron cylinder, open at both ends, which can be raised or lowered as required; it slides in or out like the tube of a spy-glass, and the joint or hole is kept air-tight. Then, instead of letting the hemisphere descend, the cylinder is lowered; and on the air being compressed into the vessel, the water is driven out both of the hemisphere and the cylinder, and the diver can descend from the hemisphere and go down the cylinder to the bottom of the river, just as he would go down a well.

E. Ah! but how would he get into the great hemisphere?

F. By a very clever contrivance. The great upper chamber is furnished with a small antechamber, intercommunicating by a large valve or air-tight door, and having another similar door as an entrance from without. It is obvious to you that if both doors are opened, all the compressed air would escape, and the water, rushing in, would fill the vessels as high as the level of the river. But, when the workman enters the antechamber from without, he carefully closes the door behind him; he then opens the door that intercommunicates with the large chamber; some of the compressed air, but not much, enters, and diffuses itself in the small chamber, making the atmosphere of both of the same density. He now shuts the door behind him, and goes down the cylinder.

E. I quite understand the ingenious plan; and can see that if the antechamber is small in proportion to the great chamber, very little air will be lost for each person that enters, providing he is careful to shut the door after him.

F. Another application of this principle is in the construction of the piers of bridges. At Rochester, for instance, it had been long necessary to erect a new bridge; and the cost of the foundation would have been very great, and the more so in this instance, from the peculiar circumstances of the bottom of the river. *Diving-cylinders*, if we may call them by that name, came to the rescue. A strong iron cylinder is sunk vertically; another is attached to it, and another and another, according to the depth of the river and the progress of the works. Air-tight doors intercommunicate between each; the first or upper cylinder is the antechamber, and the others, forming a kind of well,

are the large chamber. When the lowermost had comfortably reached the bottom of the river, and was rightly adjusted over the spot where it was permanently to stand, the work of excavation or digging of the foundation commenced. The workman enters by the antechamber or upper cylinder, and descends, air having been previously forced in so as to expel the water. He digs away the earth, and the heavy mass of iron sinks by its own weight; he conveys away the soil as he collects it, by way of the antechamber, and returns for more; and so he goes on until the whole has sunk so much that the top of the highest cylinder has nearly reached down to the water's edge; when it is lengthened by the addition of another cylinder, and so on.

C. You spoke of the spot where this set of cylinders was *permanently* to stand. Is it not, then, removed when the work is done?

F. No. It constitutes the means of doing the work, and is the very work itself. It is one of several columns, each similar, that form the permanent works of the bridge. It is constructed with the necessary strength, and is sunk through the soft bottom of the river until a hard substratum is arrived at; and thus has a solidity which could not otherwise be obtained except at enormous cost.

CONVERSATION XXI.

Of the Diving-Boat.

F. I have now to describe to you a means of descending to the bottom of the sea, and there remaining, without any communication with the surface; but with the means of sustaining life comfortably, and of rising again, when required.

C. What! of sinking and of rising again without help from above?

F. Yes; strange as it may at first seem, this is safely and readily accomplished by Dr. Payerne, a French engineer, by means of the *diving-boat*, invented by him. It is not a boat, as far as its powers of progression are concerned; for it must be towed to the spot where the descent is to be made. Its floating properties alone give it a claim to the name of *boat*. It is an iron vessel, some 40 feet in length, and 5 or 6 feet in diameter at its thickest part, terminating toward the ends in blunt points; in shape not altogether unlike an egg, only longer in proportion to its diameter. Internally, there is a centre chamber, about 15 feet long, and which can accommodate some eight or nine workmen. Each end of the vessel is occupied by a strongly

constructed air-tight chamber. The air-chambers are similar; and the boat is prepared for service by compressing within these chambers a large quantity of air,—so large a quantity, that it will not only furnish a supply for the gang of men sufficient for a day's consumption, but enough also for other important services. The entrance to the centre chamber is by a door or man-hole at the top. Over the door is an iron arch, sustaining a pulley. When the men have entered, they close the door after them, and a man outside passes a rope from it over the pulley, and hauls it up tight, while the divers seal themselves in their prison, by screwing the door close, so as to make it water-tight.

C. But I do not see how they are to sink themselves, and, when sunk, how they are to get out without letting the water in; and, least of all, how they are to rise to the surface when their work is done.

F. I will describe these operations each in turn.—The buoyancy of the vessel is such that, although of iron, it floats with its living freight; but it is obvious to you that it would sink if it were overloaded.

E. Of course it would; but how can the divers, screwed in as they are, take in ballast and overload it so as to sink themselves?

F. Here comes in the beauty of the invention. The centre chamber is furnished with forcing-pumps. By means of these the divers pump water and force it into the air-vessels, which is no easy matter, inasmuch as the highly condensed air, with which they are pre-occupied, offers very great resistance to the entrance of anything else. However, the pumps are equal to the duty required; and in proportion as water is forced in, first at one end and then at the other, the whole machine becomes heavier; and at last, when too heavy to float, it quietly descends to the bottom.

E. But they are in the dark, and they cannot get out.

F. I should have told you that there are some little windows in the roof. As to getting out, they have merely to lift up one or more of the trap doors, with which the bottom is furnished, or they may open the bottom itself in one large trap-door.

C. What! and let all the water in upon them?

F. You forget that the space is already occupied by air. On communication being made with the water, some portion enters and condenses the air; and according to the depth and other circumstances, more water would readily enter than is convenient. But the highly charged air-magazines are at hand to prevent this. The divers have merely to open a valve, and allow

the imprisoned air to escape into the centre chamber, until, by its high state of elasticity, it drives back the water.

E. And, I suppose, as they consume the air by breathing, they let in fresh supplies?

F. They do: but there is something else to accomplish in order to sustain life. You are aware that the air, which we expire or breathe out, is very different from what we inspire or breathe in. In breathing, we consume oxygen gas from the atmosphere, and we give out carbonic acid gas, which is the oxygen we took in united with carbon or charcoal from the body. This gas will not sustain life; it is virtually poison.

C. Then the air the men have to breathe must contain very much of this bad gas?

F. It does; but it fortunately happens that both lime and water are very fond of this gas: it dissolves readily in water, and it unites with lime and forms chalk. The men, therefore, take down with them a good pailful of lime-water, and a pair of bellows, with a nozzle like that of a watering-pot. They put the nozzle of the bellows into the water, and now and then blow away lustily, so that the air of their chamber is passed through the lime-water, where it leaves behind its carbonic acid gas, and so is purified. It is even not always necessary to use the bellows; for, when there is a good current of water flowing, it takes up the carbonic acid in passing.

E. Now do tell us how they get up to the surface; I am so anxious to know; for they seem to me perfectly helpless.

F. You heard me speak of the difficulty there was in forcing water into the air-cells, so as to sink the vessel: and you may readily suppose that what was forced in with so much difficulty can easily be got out; and so it is: for the compressed air still contends strongly against the intruding load of water; and no sooner do the divers open the proper valves, than the water is forced out, and the boat, being lightened of its load, readily rises to the surface. The men bring up with them whatever treasure or debris they may have collected during their immersion. They generally work eight hours a day, in two turns of four hours, and do this without inconvenience. Improvements are daily being made in this apparatus, so that many new applications may soon be discovered.

CONVERSATION XXII.

Of Pumps.

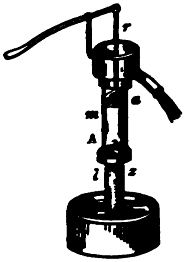


Fig. 22.

F. Here is a glass model of a common pump, which acts by the pressure of the atmosphere on the surface of the water in which it is placed.

E. Is this like the pump below stairs?

F. The principle is exactly the same: *a* represents a ring of wood or metal, with pliable leather fastened round it to fit the cylinder A. Over the whole is a valve of metal, covered with leather, of which a part serves as a hinge for the valve to open and shut by.

C. What is a valve, sir?

F. It may be described as a kind of lid or trap-door, that opens one way into a tube, but which the more forcibly it is pressed the other way, the closer the aperture is shut; so that it either admits the entrance of a fluid into the tube, and prevents its return; or permits it to escape, and prevents its re-entrance.

Attend now to the figure: the handle and rod *r* end in a fork which passes through the piston, and is screwed fast to it on the under side. Below this, and over a tube of a smaller bore, as *z*, is another valve *v* opening upward, which admits the water to flow up, but not to run down.

E. That valve is open now, by which we see the size of the lower tube, but I do not perceive the upper valve.

F. It is supposed to be shut, and, in this situation, the piston *a* is drawn up, and being air-tight, the column of air on its top is removed, and consequently leaves a vacuum in the part of the cylinder between the piston and the lower valve.

C. I now see the reason of lifting up the pump handle: because the piston then goes down to the lower valve, and by its ascent afterwards the vacuum is produced.

F. And the closer the piston is to the lower valve, the more perfect will be the vacuum.

You know there is a pressure of the air on all bodies, on or near the surface of the earth, equal to about 14 or 15 pounds on every square inch. This pressure upon the water in the well, into which the lower end of the pump is fixed, forces the water into the tube *z*, above its level, as high as *l*.

C. What becomes of the air that was in that part of the tube?

F. You shall see the operation. I put the model into a dish of water, which now stands at a level in the tube *z* with the water in the dish. I draw up the piston *a*, which causes a vacuum in the cylinder A.

E. But the valve *v* opens, and now the water has risen as high as *l*.

F. Because when the air was taken out of the cylinder A there was no pressure upon the valve *v* to balance that beneath it; consequently, the air in the tube *z* opened its valve *v*, and and part of it rushed into A. But as soon as part of the air had left the tube *z*, the pressure of the atmosphere upon the water in the dish was greater than that of the air in the tube; and, therefore, by the excess of pressure, the water is driven into it as high as *l*.

C. The valve *v* is again shut.

F. That is, because the air is diffused equally between the level of the water at *l* and the piston *a*, and therefore the pressures over and under the valve are equal. And the reason that the water rises no higher than *l* is, that the air in that space is not only equally diffused, but is of the same density as the air without. Push down the piston *a* again.

E. I saw the valve in the piston open.

F. For the air between the piston and valve *v* could not escape by any other means than by lifting up the valve in *a*. I will draw up the piston.

C. The water has risen now above the valve *v* as high as *m*.

F. I dare say you can tell the cause of this.

C. Is it this? by lifting up the piston, the air that was between *l* and the valve *v* rushed into A, and the external pressure of the atmosphere forced the water after it.

F. And now that portion of air remains between the surface of the water *m* and the piston. The next time the piston is forced down all the air must escape, the water will get above the valve in the piston, and, in raising it up again, it will be thrown out of the spout.

E. Will the act of throwing that out open the lower valve again, and bring in a fresh supply?

F. Yes; every time the piston is elevated, the lower valve rises, and the upper valve falls; but every time the piston is depressed the lower valve falls, and the upper one rises.

E. This method of raising water is so simple and easy, that I wonder people should take the trouble of drawing water up from deep wells, when it might be obtained so much easier by a pump.

F. I was going to tell you that the action of pumps, so beau-

tiful and simple as it is, is very limited in its operation. If the water in the well be more than 32 or 33 feet from the valve r, you may pump for ever, but without any effect.

E. That seems strange: but why 33 feet in particular?

F. I have already told you, that it is the weight of the atmosphere which forces the water into the vacuum of the pump. Now, if this weight were unlimited, the action of the pump would be so likewise; but the weight of the atmosphere is only about 14 or 15 pounds on every square inch; and a column of water, of about 33 feet in height, and whose surface is one square inch, weighs also 14 or 15 pounds; as you now know from the computations you made a few days ago.

C. Then the weight of the atmosphere would balance or keep in equilibrio only a column of water 33 feet high, and consequently could not support a greater column of water, much less have power to raise it up.

F. The operation is effected entirely by the pressure of the atmosphere on the surface of the water, by which it is forced into the space formerly occupied by the air. This is not a sudden operation: it requires many strokes of a pump to withdraw as much air as to allow the water to rise so many feet above the surface.

E. A pump, then, would be of no use in the deep wells which we saw near the coast in Kent.

F. None at all; the piston of a pump should never be set to work more than 28 feet above the water, because, at some periods, the pressure of the atmosphere is so much less than at others, that a column of water something more than 28 feet, will be equal to the weight of the air.

C. What is the principle of the *centrifugal pump*, which raised so much water to so great a height, and which excited so much attention at the Great Exhibition?

F. It consists of a hollow wheel, traversed by vanes. The water *enters* the wheel by the axis, which is hollow and acts as a suction-pipe; and *leaves* the wheel at the circumference. The latter is partly enclosed in a kind of case, from which a pipe proceeds upward. When the wheel is rotated in water, the water rapidly enters at the axis, and being prevented returning to the reservoir by the envelope, much of it is forced to ascend the pipe attached thereto. Considerable ingenuity has been exercised in determining the most profitable form for the vanes. Appold's pump was one foot in diameter; its vanes were curved; *it held* one gallon, and could discharge its contents 1400 times per minute. It is adapted for lifting much water to a moderate

height. It lifted 2100 gallons in a minute 8¼ feet high, and 432 gallons 26½ feet high with about an equal number of revolutions.

CONVERSATION XXIII.

Of the Forcing-Pump, Fire-Engine, Rope-Pump, Chain-Pump, and Hydraulic Press.

C. Why is this called the forcing-pump?

F. Because it not only raises the water into the barrel like the common pump, but afterwards forces it up into the reservoir K K.

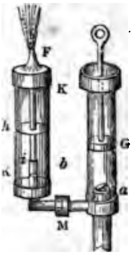


Fig. 33.

E. How is that operation performed, papa?

F. The pipe and barrel are the same as in the other pump, but the piston G has no valve; it is solid and heavy, and made air-tight, so that no water can get above it.

C. Does the water come up through the valve *a*, as it did in the last?

F. By raising up the piston, or, as it is generally called, the plunger, G, a vacuum is made in the lower part of the barrel, into which, by the pressure of the air, the water rushes from the well as you see.

E. And the valve is shut down.

F. The water not being able to go back again, and being a fluid that is nearly incompressible, when the plunger is forced down, escapes along the pipe M, and through the valve *b* into the vessel K.

C. Though the water stands no higher than *h*, it flows through the pipe F to some height.

F. The pipe F *i* is fixed into the top of the vessel, and is made air-tight, so that no air can escape out of it after the water is higher than *i*, the edge of the pipe.

E. Then the whole quantity of air, which composed the space F *b*, is compressed into the smaller space *h* F.

F. You are right: and therefore the extra pressure on the water in the vessel forces it through the pipe, as you see.

C. And the greater the condensation, that is, the more water you force into the vessel K, the higher the stream will mount.

F. Certainly; for the forcing-pump differs from the last in this respect, that there is no limit to the altitude to which water may be thrown, since the air may be condensed to almost any degree.

The waterworks that used to exist at London Bridge exhi-

bited a most curious engine, constructed upon the principle of the forcing-pump; the wheelwork was so contrived as to move either way, as the water ran; by these works, 140,000 hogsheads of water were raised every day.

E. Is there any rule to calculate the height to which an engine will throw water?

F. If the air's condensation be double that of the atmosphere, its pressure will raise water 33 feet; if the condensation be increased threefold, the water will reach 66 feet; and so on, allowing the addition of 33 feet in height for every increase of *one* to the number that expressed the air's condensation.

C. Are fire-engines made in this manner?

F. They are all constructed on the same principle, but there are two barrels, by which water is alternately driven into the air-vessels; by this means the condensation is much greater; the water rushes out in a continued stream, and with such velocity, that a raging fire is rather dashed out than extinguished by it. Garden-engines are also construeted on a principle similar to that whieh we have been describing.

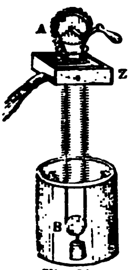


Fig. 34.

Figure 34. is the representation of a method of raising water from wells of considerable depth.

It consists of three hair-ropes passing over the pulleys A and B, which have three grooves in each. The lower pulley B is immersed in the water, in which it is kept suspended by a weight. The pulleys are turned round with great velocity by multiplying wheels, and the cords, in their ascent, carry up a considerable quantity of water, which they discharge into the box or reservoir Z, from whence, by pipes, it may be conveyed elsewhere. The ropes must not be more than about an inch apart.

E. What is the reason of that, papa?

F. Because, in that case, a sort of column of water will ascend between the ropes, to which it adheres by the pressure of the atmosphere.

C. Ought not this column, in its ascent, to fall back by its own gravity?

F. Yes; and so it would, did not the great velocity of the ropes occasion a considerable rarefaetion of the air near them, consequently the adjacent parts of the atmosphere pressing towards the vacuity, tend to support the water.

E. Can any considerable quantity of water be raised in this way?

F. At Windsor, a pump of this kind will raise, by the efforts

of one man, about 9 gallons of water in a minute, from a well 95 feet deep. In the beginning of motion, the column of water adhering to the rope is always less than when it has been worked for some time, and the quantity continues to increase till the surrounding air partakes of its motion. There is also another of these pumps at the same place, which raises water from the well in the Round Tower 178 feet in depth. You may see a pump of this kind in daily operation at the Polytechnic Institution.

C. Pray what is a chain-pump?

F. It consists of two square or cylindrical barrels, through which a chain passes, having a number of flat pistons, or valves, fixed upon it, at proper distances. The chain passes round wheel-work, fixed at one end of the machine. A whole row of the pistons, which go free of the sides of the barrel, is always rising when the pump is at work; and, as this machine is generally worked with great velocity, they bring up a full bore of water in the pump.

E. For what purpose is the chain-pump chiefly used?

F. It has been used in the navy to prevent the fatal accidents which have sometimes happened on shipboard by the choking of pumps with valves.

C. Is it confined to nautical uses?

F. No; it is adapted to the raising of water in all situations, where it happens to be mixed with sand, or other substances, which destroy common pumps, as in alum-works, in mines, in quarries, &c. In its present improved state, it is simple and durable, and may be made of metal or wood, at a moderate expense.

E. You told us, some time ago, that, when we had seen the nature and understood the construction of valves, you would explain the action of Bramah's hydraulic press.

F. This is a good time for the purpose, and with it I shall conclude our Hydrostatical Conversations.

In this figure *e* is a strong cast-iron cylinder, ground very accurately within, that the piston *a* may fit exceedingly close and well. I need scarcely tell you, that the little figure represents a forcing-pump, with a solid plunger *c*, and a valve *n*, that opens upwards, through which the water is brought into the pipe *o*. By bringing down the plunger *c*, the water in *o* is forced through the valve

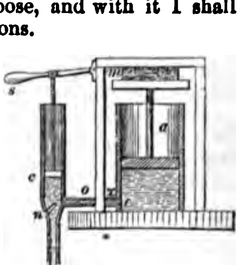


Fig. 35.

x into the bottom of the cylinder, and thereby drives up the plunger *a*.

C. What does *m* represent?

F. A bundle of hay, or bag of cotton, or any other substance that it may be desirable to bring into a compass twenty or thirty times less than it generally occupies.

E. I see now the whole operation: the more water there is forced into *o*, the higher the plunger is lifted up, by which the substance *m* is brought into a smaller space.

F. Every time the handle *s* is lifted up, the water rushes in from the well or cistern, and when it is brought down, the water must be forced into the cylinder. The power of this engine is only limited by the strength of the materials of which it is made, and by the force applied to it.

Mr. Walker says, a single man working at *s* can, by a machine of this kind, bring hay, cotton, &c., into twenty times less compass than it was before; consequently a vessel carrying light goods may be made to contain twenty times more packages, by means of the hydraulic press, than it could without its assistance.

C. I have heard you say that the iron tubes of the great Menai Bridge were lifted into their places by an hydraulic press: this must have been a most powerful machine.

F. Indeed it was; it is the largest ever constructed. The ram is 20 inches in diameter, and has a stroke of 6 feet. It raised a dead weight of 1144 tons one lift or 6 feet in half an hour: for this it used 81$\frac{1}{2}$ gallons of water; and the power employed for pumping in this supply was a small steam-engine of only 15 horse power. The press itself weighs 60 or 70 tons, and was placed above the tube, which was suspended from it by chains. The pressure on each square inch of the pump was about 4 tons, and is sufficient to raise a column of water about 5$\frac{1}{4}$ miles.

PNEUMATICS.

CONVERSATION I.

OF THE NATURE OF AIR.

Father — Charles — Emma.

F. The branch of natural philosophy called Pneumatics treats of the nature, weight, pressure, and spring of the air we breathe, and of the several effects dependent upon these properties.

C. You told us, a few days ago, that the air, though invisible, is a fluid; but it surely differs much from the fluids upon which you conversed, when treating of hydrostatics.

F. It does so; but recollect the terms by which we defined a fluid.

C. You distinguished a fluid as a body, the parts of which yield to the least pressure.

F. The air, in which we live and move, will answer to this definition. Since we are continually immersed in it, as fish are in water, if the parts did not yield to the least force, we should be constantly reminded of its presence by the resistance made to our bodies.

E. In a still, calm day, when one can scarcely discern a single leaf in motion, it is difficult to conceive of the existence of such a fluid; but when

> Down at once,
> Precipitant, descends a mingled mass
> Of roaring winds, (THOMSON'S *Summer*)

no doubt can remain of the existence of some mighty unseen power.

C. But I am not quite satisfied that the air is such a body as you have described.

F. I do not wish to proceed a single step till I have made your mind easy upon this head. You see how easily these gold and silver fish move in the water; can you explain the reason of it?

C. Is it not by the exertion of their fins?

F. A fish swims by the help of his fins and tail; and fish in general are nearly of the same specific gravity with water. Take

away the water from the vessel, and the fish would have still the use of their fins and tail, at least for a short period.

E. And they would flounder about the bottom.

F. Now consider the case of birds, how they fly; the swallow, for instance, glides as smoothly along in the air as fish do in the water; but if I were to put a bird, or even a butterfly, under a glass receiver, however large, and take away the air, they would have no more use of their wings than fish have of their fins when out of water. You shall see the experiment in a day or two.

E. And would they die in this situation, as fish die when taken from their natural element, the water?

F. The cases are precisely similar. Some fish, as the carp, the eel, and almost all kinds of shell-fish, will live a considerable time out of water; so some creatures, which depend upon air for existence, will live a long time in an exhausted receiver; a butterfly, for instance, will fall to the bottom, apparently lifeless; but admit the air again into the receiver, and it will revive; whereas experiments have been made on mice, rats, birds, rabbits, &c., and it is found that they will live without air but a very few minutes.

C. Can fish live in water, from which the air is wholly excluded?

F. The air is, in fact, as necessary to their existence as it is to ours. Besides their fins, fish have the use of an air-vessel, which gives them full command of their various motions in all depths of water, which their fins without it would not be equal to.

E. What do you mean by an air-vessel?

F. It is a small bladder of air, so disposed within them, that by the assistance of their muscles, they are able to contract and dilate it at pleasure. By *contraction* they become specifically heavier than the water, and sink; by *dilatation* they are lighter and rise to the surface more readily.

C. Are these operations effected by the external air?

F. Very much so: for if you take away the air from the water in which a fish is swimming, it will no longer have the power of contracting the air-vessel within, which will then become so expanded as to keep it necessarily on the surface of the water, evidently to its great inconvenience and pain.

If the air-bladder of a fish be pricked or broken, the fish presently sinks to the bottom, unable either to support or raise itself up again. Flat fishes, as soles, plaice, &c., which always lie grovelling at the bottom, have no air-bladder.

CONVERSATION II.

Of the Air-Pump.

E. You have told us, papa, of taking away the air from vessels will you show us how that is performed?

F. I will; and I believe it will be the most convincing method of proving to you that the air is such a body as I have described.

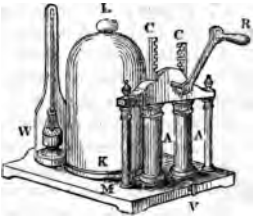


Fig. I.

This instrument is called an air-pump, and its use is to exhaust or draw away the air from any vessel, as the glass receiver L K.

C. Does it act like the common pump?

F. So much so, that, if you comprehend the nature and structure of the one you will find but little difficulty in understanding the other. I will, however, describe the different parts. A A are two strong brass barrels, within each of which, at the bottom, is fixed a valve, opening upwards; these valves communicate with a concealed pipe that leads to K. The barrels include also movable pistons, with valves opening upwards; in fact, just as the valves of the ordinary pumps.

E. How are they moved?

F. To the upper parts of the pistons is attached rackwork, part of which you see at C C: these racks are moved up and down by means of a little cog-wheel, turned round by the handle R.

C. You turn the handle but half way round.

F. And by so doing, you perceive that one of the racks rises and the other descends.

E. What is the use of the screw V?

F. It serves to readmit air into the receiver when it is in a state of exhaustion; for without such a contrivance the receiver could never be moved out of its place, after the air was once taken from beneath it; but you shall try for yourselves. I first place a slip of wet leather, or a little grease, under the edge of the receiver, because the brass plate is liable to be scratched, and the smallest unevenness between the receiver and plate would prevent the success of our experiment. I have turned the handle but a few times; try to take away the receiver.

C. I cannot move it.

F. I dare say not; for now the greater part of the air is taken

from under the receiver, consequently it is pressed down with the weight of the atmosphere on the outside.

E. Pray explain how the air was taken away.

F. By turning the winch a half way round I raised one of the pistons, and thereby left a vacuum in the lower part of the barrel, and a portion of the air in the receiver rushed through the pipe into the empty barrel. I then turned the winch the other way, which raised the other piston: and a vacuum would be left in that barrel did not another portion of air rush from the receiver into it.

C. When the first piston descended, did the air in the barrel open the little valve, and escape by the rack *c*?

F. It did: and by the alternate working of the pistons, so much of the air is taken away, that the quantity left has not force enough to raise the valve.

C. Cannot you take all the air from the receiver?

F. Not by means of the air-pump.

E. What is the reason that a mist comes on the inside of the glass receiver while the air is exhausting?

F. The mist is watery vapour. The air is never absolutely dry: it always contains more or less water: according to the temperature or the degree of rarefaction, it is able to take up a certain quantity, and retain it in an invisible form; but if this quantity be exceeded, it is manifested in the form of vapour. In winter, for instance, when your breath mixes with the cold air, the water given off in your breath becomes visible, because the breath is chilled, and cannot then retain so much water in solution: in summer, you do not see your breath. So, in the present case, the air before the pumping commenced has in it no more water than it could dissolve in an invisible state; but as the pumping made the remaining air more rarefied, it could not dissolve the same proportion of water. It is explained by the sudden expansion of the air that is left in the receiver.

C. You have not told us the use of the smaller receiver *w*, with the bottle of quicksilver within it.

F. By means of the concealed pipe there is a communication between this and the large receiver, and the whole is intended to show to what degree the air in the large receiver is exhausted. It is called the small barometer-gauge, the meaning of which you will better understand when the structure of the barometer is explained. I will now show you an experiment or two, by which the resistance of the air is clearly demonstrated.

E. Are these mills for the purpose?

F. Yes, they are. the machine consists of two sets of vanes, *a*

and *b*, made equally, and to move on their axes with the same freedom.

C. But the vanes of *a* are placed breadthwise, and those of *b* are edgewise.

F. They are so placed to exhibit in a striking manner the resistance of the atmosphere; for as the little mill *b* turns, it is resisted only in a small degree, and will go round a much longer time than the other, which, in its revolutions, meets the air with its whole surface. By means of the spring *c* resting against the slider *d* in each mill, the vanes are kept fixed.

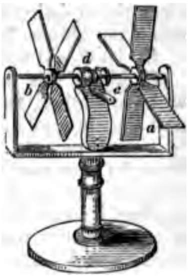


Fig. 2.

E. Shall I push down the sliders?

F. Do so; you see that both set off with equal velocities.

C. The mill *a* is evidently declining in swiftness, while the other goes on as quickly as ever.

F. Not quite so; for in a few minutes you will find them both at rest.

Now we will place them under the receiver of the air-pump; and by a little contrivance, we shall be able to set the mills in motion after the air is exhausted from the receiver; and then, as there is no sensible resistance against them, they will both move round a considerable time longer than they did in the open air, and the instant that one stops the other will stop also.

E. This experiment clearly shows the resisting power of the air.

F. It shows also that its resistance is in proportion to the surface opposed to it: for the vane which met and divided the air by the edge only continued to move the longest, while they were both exposed to it; but when that is removed, they both stop together, because there is nothing now to retard their motion but the friction on the pivots, which is the same in both cases. Take this shilling and a feather: let them both drop from your hand at the same instant.

C. The shilling is soon at rest at my feet, but the feather continues floating about. Is the feather specifically lighter than air?

F. No: for if it were it would ascend till it found the air no heavier than itself; whereas, in a minute or two, you will see the feather on the floor as well as the shilling: it is, however, so light, and presents so large a surface to the air, in comparison to its weight, that it is considerably longer in falling to the ground than heavier bodies, such as a shilling or a guinea. Take

away the resisting medium, and they will both reach the bottom at once.

E. How will you do that?

F. Upon this brass flap I place the shilling and the feather, and having turned up the flap, and shut it into a small notch, I fix the whole in a small receiver, with a piece of wet leather between the receiver and brass. I will now exhaust the air from under the receiver, by placing it over the air-pump, and if I turn the wire *f* a little, the flap will slip down, and the shilling and feather will fall with equal velocities.

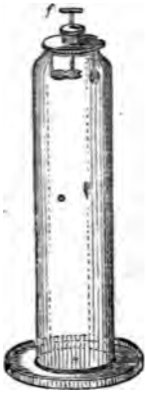


Fig. 3.

C. They are both at the bottom, but I did not see them fall.

F. While I repeat the experiment, you must look steadfastly to the bottom, because the motion is too rapid and the distance too small for you to trace their motion; but, by keeping your eye at the bottom, you will see the feather and shilling arrive at the same instant.

Fig. 4.

In this glass tube is some water, but the air is taken away, and the glass completely closed. Turn it up quickly, so that the water may fall on the other end.

E. It makes a noise like the stroke of a hammer.

F. And for that reason it is usually called the philosophical hammer. The noise is occasioned through the want of air to break the fall: for if I take another glass, in all respects like it, but having the air inclosed in it, as well as water, you may turn it as often as you please with hardly any noise.

C. Perhaps the air breaks the fall of the water by dividing its particles.

F. It acts, with respect to water, as water acts with regard to the fall of any other substance thrown into it; it impedes the velocity of the falling body.

CONVERSATION III.

Of the Torricellian Experiment.

C. If, by means of the air-pump, you cannot perfectly exhaust the air from any vessel, by what means is it done?

F. If I fill this glass tube, which is 36 inches long, with mercury, and, having placed my finger on the end to prevent the mercury escaping, thrust it into a cup of mercury, you will

observe that some of the mercury runs out, and six or seven inches of the tube are left free of mercury. There is no air present in that space except the small portion that has been present among the mercury. But if, further, I had taken the precaution to have boiled the mercury, both before placing it in the tube, and also when in the tube, so as to have expelled from it all air, the space would be free of air, and thus far a perfect vacuum.

E. Could not the air get in when you took away your thumb?

F. You saw that I did not remove my thumb till the open end of the tube was wholly under the quicksilver; therefore no air could get into the tube without first descending through the quicksilver: now you know that a lighter fluid will not descend through one that is heavier, and, consequently, it is impossible that any air should be in the upper part of the tube, if the quicksilver were carefully purified beforehand.

C. What makes the quicksilver stand at that particular height?

F. Before I answer this, tell me the reason why water cannot be raised by means of a common pump higher than about 32 or 33 feet?

C. Because the pressure of the atmosphere is equal to the pressure of a column of water so many feet in height.*

F. And the pressure of a column of quicksilver 29 or 30 inches long, a little more or less, according to the variation of the air, is equal to the pressure of a column of water 32 or 33 feet high, and consequently equal to the pressure of the whole height of the atmosphere.

E. Is then the mercury in the tube kept suspended by the weight of the air pressing on that in the cup?

F. It is.

E. If you could take away the air from the cup, would the quicksilver descend in the tube?

F. If I had a receiver long enough to inclose the cup and tube, and were to place them on the air-pump, you would see the effect that a single turn of the handle would have on the mercury; and, after a very few turns, the quicksilver in the tube would be nearly on a level with that in the cup.

I can show you, by means of this syringe, that the suspension of the quicksilver in the tube is owing to nothing but the pressure of the air.

C. What is the structure of the syringe?

F. If you understand in what manner a common water-squirt acts, you will be at no loss about the syringe, which is made like it.

* See Hydrostatics, Conversation XXII.

C. By dipping the small end of a squirt in water, and lifting up the handle, a vacuum is made, and then the pressure of the the air on the surface of the water forces it into the squirt.

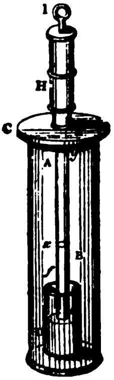


Fig. 5.

F. That is the proper explanation. This vessel D, containing some quicksilver, and the small tube *g f*, 38 inches long, open at both ends, immersed in it, are placed under a large receiver A B; the brass plate C, put upon it with a piece of wet leather, admits the small tube to pass through it at *e.* I will now screw the syringe H on the tube *g f*, and, by lifting up the handle I, a partial vacuum is made in the tube; consequently the pressure of the air in the receiver upon the mercury in the cup D forces it up into the little tube as high as *x*, just in the same manner as water follows the piston in a common pump.

E. But is not this rise of the quicksilver in the tube owing to the suction of the syringe?

F. To prove to you that it is not, I place the whole apparatus over the air-pump, and exhaust the air out of the receiver A B. This operation, you must be sensible, has not the smallest effect on the air in the syringe and little tube; but you nevertheless observe, that the mercury has again fallen into the cup D; and the syringe might now be worked for ever without raising the mercury in the tube; but admit the air into the receiver, and its action upon the surface of the quicksilver in the cup will force it instantly into the tube.

This is called the Torricellian experiment, in honour of Torricelli, a learned Italian, and a disciple of Galileo, who invented it, and who was the first person that discovered the pressure and weight of the air.

CONVERSATION IV.

Of the Pressure of the Air.

C. It seems very surprising that the air, which is invisible, should produce such effects as you have described.

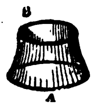


Fig. 6.

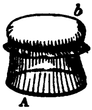
F. You have *seen* some effects in proof of this; you shall now *feel* some proof. Place this glass A B, open at both ends, over the hole of the pump plate, and lay your hand close upon the top B, while I turn the handle of the pump a few times.

C. It hurts me very much: I cannot take my hand away.

F. By letting in the air I have released you. The pain was occasioned by the pressure of the air on the outside of your hand, that being taken away from under it which served to counterbalance its weight.

This is a larger glass of the same kind; over the large end I tie a piece of wet bladder, *b*, very tight, and will place it on the pump, and take the air from under it.

b



A

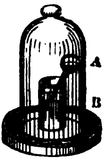
Fig. 7.

E. Is it the weight of the air that bends the bladder so much?

F. Certainly: and if I turn the handle a few more times it will burst.

C. It has made a report as loud as a gun.

F. A piece of thin flat glass may be broken in the same manner. Here is a glass bubble with a long neck; which I put into a cup of water B, and place them under a receiver on the plate of the air-pump, and, by turning the handle, the air is not only taken from the receiver, but that in the hollow glass ball will make its way through the water and escape.



A

B

Fig. 8.

E. Is it the air which occasions the bubbles at the surface of the water?

F. It is. Now the bubbling is stopped, and therefore I know that as much of the air is taken away as can be got out by means of the pump. The hollow ball is still empty; but by turning the screw V of the pump (fig. 1.), the air rushes into the receiver and presses upon the water, thereby filling the ball with the fluid.

C. It is not quite full.

F. That is because the air could not be perfectly exhausted, and the little bubble of air at the top is what, in its expanded state, filled the whole glass ball, and now, by the pressure of the external air, it is reduced into the size you see it.

Another very simple experiment will convince you that suction has nothing to do with these experiments. On the leather of the air-pump, at a little distance from the hole, I place lightly this small receiver *x*, and pour a spoonful or two of water round the edge of it. I now cover it with a larger receiver A B, and exhaust the air.

A

B

Fig. 9.

E. I see by the bubbles round the edge of the small receiver that the air is making its way from under it.

F. I have pretty well exhausted all the air; can you move the large receiver?

C. No; but by shaking the pump I see the little one is loose.

F. The large one is rendered immovable by the pressure of the external air. But the air being taken from the inside of both glasses, there is nothing to fasten down the smaller receiver.

E. But if suction had anything to do with this business, the little receiver would be fast, as well as the other.

F. Turn the screw v of the air-pump (fig. 1.) quickly. You hear the air rushing in with violence.

C. And the large receiver is loosened again.

F. Take away the smaller one, Emma.

E. I cannot move it with all my strength.

F. Nor could you lift it up if you were much stronger than you are. For by admitting the air very speedily into the large receiver, it pressed down the little one before any air could get underneath it.

C. Besides, I imagine you put the water round the edge of the glass to prevent the air from rushing between it and the leather.

F. You are right; for air, being the lighter fluid, could not descend through the layer of water in order to ascend into the receiver. Could suction produce the effect in this experiment?

C. I think not; because the little receiver was not fixed till after what might be thought suction had ceased to act.

E. How will you get the small one away?

F. As I cannot *raise* it, I must slide it over the hole in the brass plate; and now the air gets under it, there is not the smallest difficulty.

CONVERSATION V.

Of the Pressure of the Air.

C. I think I know an instance in which suction operates. It is an experiment that I have made many times.

I fasten a string in the centre of a round piece of leather, which has been thoroughly soaked in water, I press it on a flat stone, and by pulling at the string the leather draws up the stone, although it be not more than two or three inches in diameter, and the stone weighs several pounds. Surely this is suction.

F. I should say so too, if I could not account for it by the

pressure of the atmosphere. By pressing the wet leather on the stone you displace the air, then by pulling the string a vacuum is left at the centre, and the pressure of the air about the edges of the leather is so great, that it requires a greater power than the gravity of the stone to separate them.

I have seen you drink water from a spring by means of a hollow straw.

E. Yes; that is another instance of what we have been accustomed to call suction.

F. But now you know that in this operation you make a syringe with the straw and your lips, and by drawing in your breath you cause a vacuum in the hollow straw tube, and the pressure of the air on the water in the spring forces it up through the straw into the mouth.

C. I cannot, however, help thinking that this looks like suction, for the moment I cease the drawing in my breath, the water ceases to rise in my mouth.

F. That is, when there is no longer a vacuum in the straw, the pressure within is just equal to that without, and consequently the water will rest at its natural level.

I will show you another striking instance of the effects of the air's pressure. This instrument is called the *transferrer*. The screw C fits on the plate of the air-pump, and by means of the stopcocks G and H, I can take away the air from both or either of the receivers I, K at pleasure.

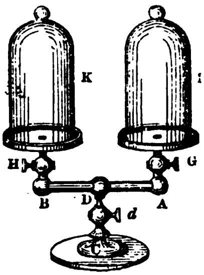


Fig. 10.

E. Is there a channel then running from C through D A B, and thence passing to the receivers?

F. There is. I will screw the whole on the air-pump, and turn the cock G, so that there is now no communication from C to the internal part of the receiver I. At present you observe that both the receivers are perfectly free. By turning the handle of the pump a few times, the air is taken away from the receiver K, and, to prevent its re-entrance, I turn the stopcock *d*. Try if you can move it.

C. I cannot; but the other is loose.

F. The pressure of the atmosphere is evidently the same on the two receivers; but with regard to the glass I, the pressure within is equal to that without, and the glass is free: in the other, the pressure from within is taken away, and the glass is fixed. In this state of the experiment you are satisfied that there is a vacuum in the receiver K. By turning the cock G, I

open a communication between the two receivers, and you hear the air that was in I rush through the channel A B into K Now try to move the glasses.

E. They are both fixed; how is this?

F. The air that was inclosed in the glass I is equally diffused between the two, consequently the internal pressure of neither is equal to the external, and therefore they are both fixed by the excess of the external pressure over the internal. In this case it could not be suction that fixed the glass I, for it was free long after what might have been thought suction had ceased to act.

C. What are these brass cups?

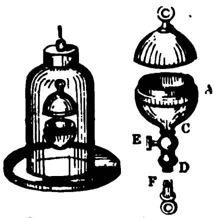


Fig. 11. Fig. 12.

F. They are called the *Magdebourg* hemispheres; I will bring the two, B A (fig. 11.) together, with wet leather between them, and then screw them by D to the plate of the air-pump; and, having exhausted the air from the inside, I turn the stopcock E, take them from the pump, and screw on the handle F. See if you two can separate them.

E. We cannot stir them.

F. If the diameter of these cups were four inches, the pressure to be overcome would be equal to 180 lbs. I will now hang them up in the receiver and exhaust the air out of it (fig. 12.), and you see they separate without the application of any force.

C. Now there is no pressure on the outside, and therefore the lower cup falls off by its own gravity.

F. With the steelyard (fig. 13.) you may try very accurately to what weight the pressure of the atmosphere against the cups is equal.*

E. For when the weight W is carried far enough to overcome the pressure on the cups, it lifts up the top one.

F. I have exhausted the air of this receiver H (fig. 14.), consequently it is fixed down to the brass plate I; to the plate is joined a small tube with a stopcock *x*; by placing the lower end of the tube in a basin of water, and turning the cock, the pressure of the atmosphere on the water in the basin forces it through the tube in the form of a fountain. This is called the fountain *in vacuo*.

To the little square bottle A *b* (fig. 15.) is cemented a screw valve, by which I can fix it on the plate of the air-pump, and

* The principle of the steelyard is explained in Mechanics, Conversation XV.

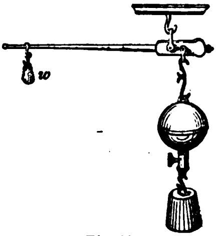


Fig. 13.

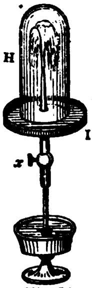


Fig. 14.

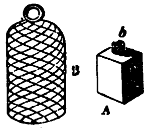


Fig. 15.

exhaust its air; and you will see that when there is no power within to support the pressure of the atmosphere from without, it will be broken into a thousand pieces.

C. Why did you not use a round phial?

F. Because one of that shape would have sustained the pressure like an arch.

E. Is that the reason why the glass receivers are able to bear such a weight without breaking?

F. It is. If mercury be poured into a wooden cup c, made of willow or ash, or a stem of thorn, and the air, taken from under it, the mercury will, by the weight of the external air, be forced through the pores of the wood, and descend like a shower of rain.

Fig. 16.

C. This is a very interesting and beautiful experiment; proving satisfactorily the great pressure of the atmosphere.

F. But there is a far more astounding illustration than this in the Atmospheric Railway.

C. Oh, papa! I am so glad you mention that; for I have so often wished to know why it is called Atmospheric Railway.

F. You will soon see why, when I have described it. You noticed how the pressure of the atmosphere burst the bladder (fig. 6.) as soon as I had removed the air from the other side of the bladder; I will now make a somewhat similar experiment by placing a glass tube on the air-pump with a well-shaped cork in its upper end; you see what happens: as soon as I take away air from below the cork, the pressure of the atmosphere forces the cork into the tube, and it moves along on the inside until it reaches the lower end. Now if the surface of the cork had been a square inch, and there had not been much friction, with what force would it have been driven down?

C. With a pressure equal to 15 lbs.

F. Yes; and therefore it could have drawn along a weight of 15 lbs. But if this weight were placed on wheels, and the wheels moved on a smooth surface, it could have been moved far more readily, on account of the favourable manner of applying the force. Here, then, you have the atmospheric railway in miniature.

C. Yes, papa; but then it must require a very large tube to draw a train of carriages weighing, as they do, many tons; because the pressure is still only 15 lbs. on a square inch when there is a perfect vacuum.

F. I am pleased to hear these objections, because it shows that you understand the subject; now it is found that a force of less than 20 lbs. will move a ton on wheels on a smooth surface like a railroad, so that you have merely to get the area of the piston and divide by 20, and you get a rough idea of the number of tons that can be drawn.

E. But, dear papa, it is all very easy to understand the cork being drawn along in the glass tube, and pulling after it anything attached; but how can a piston moving in a tube a mile or two in length be attached to the carriages?

F. You have visited the Polytechnic and seen the model there; and took a trip to Croydon when the atmospheric line existed. Between the rails is fixed an iron tube 18 inches in diameter; a slit, an inch or two wide, passes along the upper side of the groove. This slit is closed by a leathern flap armed with metal, which is fixed to one side of the slit by a kind of hinge, and shuts upon the other like a door. Charles, go outside the door and thrust in my cane, while Emma shuts the door upon the cane; now move the cane up and down, and if Emma holds it, her hand is moved by you: now fancy Charles's hand to be the piston, and Emma's to be the first carriage, and you get some idea of the mode of applying the force.

C. Aye, papa, now I see; but our parlour door, or valve, for doors are just like valves, and are sometimes called so, being of wood, is open all the way; but the leather valve would be open only a little on each side the piston; so that a very little management would keep the tube air-tight.

F. This is not the only valve that has been proposed, but I believe is the only one which is actually worked. I suppose I need scarcely tell you that the air is exhausted by large air-pumps, worked by steam-engines.

CONVERSATION VI.

Of the Weight of Air.

E. We have seen the surprising effects of the air's pressure; are there any means of obtaining the exact *weight* of air?

F. If you do not require any very great nicety, the method is very simple.

This Florence flask is fitted up with a screw, and a fine oiled silk valve at D. I will now screw the flask on the plate of the air-pump, and exhaust the air. You see, in its present exhausted state, it weighs 3 ounces and 5 grains.

Fig. 17.

C. Cannot the air get through the silk?

F. The silk, being varnished with a kind of oily substance, is impenetrable to air; and being exhausted, the pressure upon the outside effectually prevents the entrance of the air by the edges of the silk; but if I lift it up by means of this sewing-needle, you will hear the air rush in.

E. Is that hissing noise occasioned by the re-entrance of the air?

F. It is; and when that ceases, you may be sure the air within the bottle is of the same density as that without.

C. If I weigh it again, the difference between the weight now, and when you tried it before, is the weight of the quantity of air contained in the bottle: it weighs very accurately 3 ounces 19¼ grains, consequently the air weighs 14¼ grains.

F. And the flask holds a quart, wine measure.

E. Does a quart of air always weigh 14¼ grains?

F. The weight of the air is perpetually changing; therefore, though a quart of it collected on the surface of the earth weighs to-day 14¼ grains, the same quantity may, in a few hours, weigh 14½ grains, or perhaps only 14 grains, more or less.

C. You intimated that, in weighing the air, the flask could not be depended upon, if great nicety were required; what is the reason of that?

F. I told you, when explaining the operations of the air-pump, that it was impossible to obtain, by means of that instrument, a perfect vacuum. The want of accuracy in the flask experiment depends on the small quantity of air that is left in the vessel after the exhaustion is carried as far as it will go: this, however, if the pump be good, will, after 12 turns of the handle, be less than the 4000th part of the whole quantity.

E. How do you know this?

F. You seem unwilling to take anything upon my word; and in subjects of this kind you do right never to rest satisfied without a reason for what is asserted.

I suppose, then, each of the barrels of the air-pump is equal in capacity to the flask; that is, each will contain a quart; then it is evident, that by turning the handle of the pump, I exhaust all the air of one barrel, and the air in the flask becomes at the same time equally diffused between the barrel and flask; that is, the quart is now divided into two equal parts, one of which is in the flask, and the other in the barrel. By the same reason, at the next turn of the handle, the pint in the flask will be reduced to half a pint; and so it will go on decreasing, by taking away at every turn one half of the quantity that was left in by the last turn; and after the second, third, and fourth turns, it is four, eight, and sixteen times as rare as it was when you began; and after the twelfth turn it is 4096 times more rare than it was at first; so that the error is only equal to the 4096th part of the whole, which quantity may, in reasoning on the subject, be overlooked.—I will exhaust the flask again of its air, and, putting the neck of it under water, I will lift up the silk valve and fill it with water. Now dry the outside very thoroughly and weigh it.

C. It weighs 27 ounces.

F. Subtract the weight of the flask, and reduce the remainder into grains, and divide by $14\frac{1}{4}$, and you will obtain the specific gravity of water compared with that of air.

C. I have done it, and obtain something more than 800.

F. At the temperature of 32°, with the barometer standing at 30 inches, it has been found by accurate experiments, that water is 773·28 times heavier than air.

Can you tell me what the air in this room weighs? the length of the room is 25 feet, the height $10\frac{1}{2}$, and the width $12\frac{1}{2}$.

E. I multiply these three numbers together, and the answer is 3281·25; or the room contains a little more than 3281 cubic feet: now a cubic foot of water weighs nearly 1000 ounces; therefore the weight of the roomful of water would be 3,281,000 ounces; but air being nearly 800 times lighter than water, the air in the room will weigh $3{,}281{,}000 \div 800 = 4101$ oz. = 256 lb. 5 oz. It seems, however, surprising that the air, which is invisible, should weigh so much, though I cannot doubt the fact after this computation, founded, as it is, on careful experiments.

CONVERSATION VII.

Of the Elasticity of Air.

F. I have told you that air is an elastic fluid. Now it is the nature of all elastic bodies to yield to pressure, and to endeavour to regain their former figure as soon as the pressure is taken off. In projecting an arrow from your bow, you exert your strength to bring the two ends of the bow near together, but the moment you let go the strings, it recovers its former shape: the power by which this is effected is called *elasticity*.

E. Is it not by this power that India Rubber, after it has been stretched, recovers its usual size and form?

F. It is: and almost everything that you make use of possesses this property in a greater or less degree: balls, marbles, the chords of musical instruments, are all elastic, to a certain extent.

C. I understand how all these things are elastic; but do not see in what manner you can prove the elasticity of the air.*

F. Here is a bladder, which we will fill with air, and tie up its mouth to prevent its escaping again. If you now press upon it with your hands, its figure will be changed; but the moment the pressure is removed it recovers its round shape.

E. And if I throw it on the ground, or against any other obstacle, it rebounds like a ball or marble.

F. Let us now have recourse to the air-pump to exhibit some of the more striking effects of the air's elasticity. I will let a part of the air out of the bladder, and tie up its mouth again. It is now flaccid, and you may make what impression you please upon it, without its endeavouring to reassume its former figure.

E. What proof is there that this is owing to the external pressure of the air?

F. Place it under the receiver of the air-pump, exhaust the air, and see the consequences.

C. It begins to swell out; and now it is as large as when it was blown out full of air.

F. The outward pressure being in part removed, the particles of air, by their elasticity, distend, and fill up the bladder; and if it were much larger, and the exhaustion were carried farther, the same small quantity of air would fill it completely. I will now let the air in again.

E. This exhibits a very striking proof of the power and pressure of the external air, for the bladder is as flaccid as it was before.

* See Mechanics, Conversation XIII.

F. I put the same bladder into this square box without any alteration, and place upon it a movable lid, upon which I put this weight. By bringing the whole under a receiver, and exhausting the external air, the elasticity of that in the bladder will lift up the lid and weight together.

C. If you pump much more, the weight will fall against the side of the glass.

F. I do not mean to risk that: — it is enough that you see a few grains, not half a dozen, of air will, by their elasticity, raise and sustain a weight of several pounds.

Take this glass tube (represented in fig. 4.): the bore of the tube is too small for the water to run out; but if I place it under the receiver of the air-pump, and take away the external air, the little quantity of air which is at the top of the glass, will, by its elastic force, expand itself, and drive out all the water.

E. This experiment shows that a very small quantity of air is capable of filling a large space, provided the external pressure is taken off.

F. Certainly: I will take off the bladder from this glass (fig. 17, Hydrostatics). The little images all swim at the top, the air contained in them rendering them rather lighter than the water. Tie little leaden weights to their feet, and they are then pulled down to the bottom of the vessel. I now place the glass under the receiver of the air-pump, and, by exhausting the air from the vessel, that which is within the images, by its elasticity, expands itself, forces out more water, and you see they are ascending to the top, dragging the weights after them. I will let in the air, and the pressure forces the water into the images again, and they descend.

Here is an apple very much shrivelled, which, if placed under the receiver, and the external air be taken away, will appear as plump as if it were newly gathered from the tree. I will admit the air again.

C. It is as shrivelled as ever. Do apples contain air?

F. Yes, a great deal; and so, in fact, do almost all bodies that are specifically lighter than water, as well as many that are not so. It was the elastic power of the air within the apple that forced out all the shrivelled parts when the external pressure was taken away.

Here is a small glass of warm ale, from which I am going to take away the air.

E. It seems to boil, now you exhaust the air from the receiver.

F. The bubbling is caused by the air endeavouring to escape from the liquor. Let the air in again, and then taste the beer.

C. It is flat and dead.

F. You see of what importance air is to give to all our liquors their pleasant and brisk flavour, for the same will happen to wine and all other fermented fluids.

E. How is it that the air, when it was re-admitted, did not penetrate the ale again?

F. It could not insinuate itself into the pores of the beer, because it is the lighter body, and therefore will not descend through the heavier. Besides, it does not follow that it is the same sort of air which I admitted into the receiver, that was taken from the ale.

E. Are there more kinds of air than one?

F. Yes, very many. That which I took from the beer, and which gives it the brisk and lively taste, is called fixed air, or carbonic acid gas, of which there is, in general, but a very small quantity in the atmosphere.

The elasticity, or spring of air, contained in our flesh, was clearly shown by the experiment, when I pumped the air from under your hand.

C. Was that the cause of its swelling downwards?

F. It was: and it will account for the pain you felt, which was greater than, and of a very different kind from, what you would have experienced by a dead weight being laid on the back of your hand equal to the pressure of the air.

Cupping is an operation performed on this principle: the operator tells you he draws up the flesh: but if he were to speak correctly, he would say, he took away the external air from off a certain portion of the body, and then the elastic force of the air within extends, and swells out the flesh ready for the lancets.

E. When I saw you cupped he did not use an air-pump, but little glasses, to raise the flesh.

F. Glasses closed at top are now generally made use of, in which the operator holds the flame of a lamp: by the heat of this the elasticity of the air in the glass is increased, and thereby a great part of it driven out. In this state the glass is put on the part to be cupped, and as the inward air cools, it contracts, and the glass adheres to the flesh by the difference of the pressures of the internal and external air.

By some persons, however, the syringe is considered as the most effectual method of performing the operation, because by flame the air cannot be rarefied more than one half, whereas by the syringe a few strokes will nearly exhaust it.

Here is another square bottle like that before exhibited (fig. 15, p. 225.), only that it is full of air, and the mouth sealed so closely that none of it can escape. I enclose it within

the wire cage B, and in this state bring them under the receiver, and exhaust the external air.

C. With what a loud report it has burst!

E. Why did you place the wire cage over the bottle?

F. To prevent the pieces of the bottle from breaking the receiver, an accident that would be liable to happen without this precaution.

Take a new-laid egg, and make a small hole in the little end of it; then with that end downwards, place it in an ale-glass under the receiver, and exhaust the air; the whole contents of the egg will be forced out into the glass by the elastic spring of the small bubble of air which is always to be found in the large end of a new-laid egg.

E. Well, really these experiments are very delightful. How grateful do I feel to you, dear papa, for giving us this power of investigating the works of nature.

CONVERSATION VIII.

Of the Compression of Air.

F. I have already told you that water was compressible in a small degree; but the compression which can be effected with the greatest power is so very small, that, without considerable attention and nicety in conducting the experiments, it would never have been discovered. Air, however, is capable of being compressed into a very small space compared with what it naturally possesses.

E. The experiment you made by plunging an ale-glass with its mouth downwards, clearly proved that the air which it contained was capable of being reduced into a smaller space.

F. This bended tube A B C is closed at A and open at C. It is, in the common state, full of air. I first pour into it a little quicksilver, just sufficient to cover the bottom *a b:* now the air in each leg is of the same density, and as that contained in A B cannot escape, because the lighter fluid will be always uppermost, when I pour more quicksilver in at C, its weight will condense the air in the leg A B; for the air, which filled the whole length of the leg, is, by the weight of the quicksilver in C B pressed into the smaller space A *x*, which space will be diminished as the weight is increased; so that, by increasing the length of the column of mercury in C B, the air in the other leg will be more and more condensed. Hence we learn that the elastic

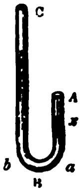


Fig. 18.

spring of air is always and under all circumstances equal to the force which compresses it.

C. How is that proved?

F. If the spring, with which the air endeavours to expand itself when it is compressed, were less than the propelling force, it must yield still farther to that force; that is, if the spring of the air in A *x* were less than equal to the weight of the mercury in the other leg, it would be forced into a yet smaller space; but, if the spring were greater than the weight pressing upon it, it would not have yielded so much; for you are well aware that action and reaction are equal, and act in opposite directions.

You can now easily understand why the lower regions of the atmosphere are more dense than those which are higher.

E. Because they are pressed upon by all the air that is above them, and therefore condensed into a smaller space.

F. Consequently the air becomes gradually thinner or rarer, till, at a considerable height, it may be conceived to degenerate to nothing. The different densities of the air may be illustrated by conceiving twenty or thirty equal fleeces of wool placed one upon another; the lowest will be forced into a less space, that is, its parts will be brought nearer together, and it will be more dense than the next; and that will be more dense than the third from the bottom, and so on till you come to the uppermost, which sustains no other pressure than that occasioned by the weight of the incumbent air.

Fig. 19.

Let us now see the effect of condensed air, by means of an artificial fountain. This vessel is made of strong copper, and is about half full of water. With a syringe that screws to the pipe B A I force a considerable quantity of air into the vessel, so that it is very much condensed. By turning the stopcock B while I take off the syringe no water can escape: and, instead of the syringe, I put on a jet, or very small tube, after which the stopcock is turned, and the pressure of the condensed air forces the water through the tube to a very great height.

C. Do you know how high it ascends?

F. Not exactly: but as the natural pressure of the air will raise water 33 feet, so if by condensation its pressure be tripled, it will rise 66 feet.

E. Why tripled? Ought it not to rise to this height by a double pressure?

F. You forget that there is the common pressure always acting against, and preventing the ascent of

the water; therefore, besides a force within to balance that without, there must be a double pressure.

C. You described a syringe to be like a common water-squirt—how are you able, by an instrument of this kind, to force in so great a quantity of air? Will it not return by the same way it is forced in?

F. The only difference between a condensing syringe and a squirt is, that, in the former, there is a valve that opens downwards, by which air may be forced through it; but the instant that the downward pressure ceases, the valve, by means of a strong spring, shuts of itself, so that none can return.

E. Will not air escape back during the time you are forcing in more of the external air?

F. That would be the case if the syringe pipe went no lower than that part of the vessel which contains the air; but it reaches to a considerable depth in the water; and, as it cannot find its way back up the pipe, it must ascend through the water, and cause that pressure upon it which has been described.

C. To what extent can air be compressed?

F. If the apparatus be strong enough, and a sufficient power applied, *atmospheric* air may be condensed several thousand times; that is, a vessel, which will contain a gallon of air in its natural state, may be made to contain several thousand gallons.

By means of a fountain of this kind, young people like yourselves may receive much entertainment with only a few additional jets, which are made to screw on or off. One kind is so formed that it will throw up and sustain on the stream a little cork ball, scattering the water all round. Another is made in the form of a globe, pierced with a great number of holes, all tending to the centre, exhibiting a very pleasing sphere of water. One is contrived to show, in a neat manner, the composition and resolution of forces explained in our Conversations on Mechanics.* Some will form cascades; and by others you may, when the sun shines at a certain height in the heavens, exhibit artificial rainbows.†

We will now force in a fresh supply of air, and try some of these jets.

E. Pray, papa, why did you lay so great stress upon *atmospheric* air being capable of a certain condensation.

F. Because other kinds of air can be so much condensed as actually to be squeezed into a liquid.

* See Mechanics, Conversation XIII.
† This phenomenon is described and explained in Optics, Conversation XVIII.

E. Do tell us how this is done.

F. Dr. Faraday, now the most distinguished philosopher for original research, was working with a certain air or gas in tubes, and observed an oily liquid appear: he repeated the experiment with carefully cleaned tubes, and the oily appearance again occurred. On examination he found that the gas had actually been condensed into this oily liquid. The gas was called chlorine.

E. How very curious! And is this the only kind of air that can be liquefied?

F. By no means; he has found that very many of the gases are capable of liquefaction under certain precautions, which you will be able to comprehend better when you have learned a little chemistry. The most remarkable, by way of illustration, is the gas contained in champagne, soda water, ale, &c., namely, carbonic acid. The materials necessary for producing this gas are placed in a strong iron vessel: the gas forms very abundantly; and as it has no means of escaping, it becomes so compressed by the continued accumulation, that at last it squeezes itself into a liquid. When the vessel is opened the liquid begins to return into gas so fast, that it produces an immense quantity of cold, as ether does when placed on your hand; and this cold actually freezes the rest of the liquid, and the gas appears in a solid form, just like snow.

E. How I should like to touch this solid air: it must be very cold.

F. Yes, dear, so cold that mercury instantly freezes in it, and becomes like lead, so that you can cut it, or hammer it on an anvil. But you would find it no easy matter to touch it, for the surface of it would expand into gas and place itself between your finger and the solid carbonic acid; but if you use a little ether to wet the solid and your finger, your finger would be instantly frostbitten. But we must not talk more of this.

E. I observed, in the upright jets, that the height to which the water was thrown was continually diminishing.

F. The reason is this: that in proportion as the quantity of water in the fountain is lessened, the air has more room to expand, the compression is diminished, and consequently the pressure becomes less, till at length it is no greater within than it is without, and then the fountain ceases altogether.

Condensed air has been proposed as a means of propelling locomotives instead of steam; it is compressed in an iron cylinder, and by proper regulations is allowed to escape, and act upon a piston.

CONVERSATION IX.

Miscellaneous Experiments on the Air-Pump.

F. I shall, to-day, exhibit a few experiments, without any regard to the particular subjects under which they might be arranged.

In this jar of water I plunge some pieces of iron, zinc, stone, &c., and you will see that, when I exhaust the external air, by bringing the jar under the receiver of the air-pump, the elastic spring of air contained in the pores of these solid substances will force them out in a multitude of globules, and exhibit a very pleasing spectacle, like the pearly dew-drops on blades of grass: but when I admit the air, they suddenly disappear.

E. This proves what you told us a day or two ago, that substances in general contain a great deal of air.

F. Instead of bodies of this kind, I will plunge in some vegetable substances, a piece or two of the stem of beet-root, angelica, &c.; and now observe, when I have exhausted the receiver, what a quantity of air is forced out of the little vessels of these plants by means of its elasticity.

C. From this experiment we may conclude that air makes no small part of all vegetable substances.

F. To this piece of cork, which of itself would swim on the surface of water, I have tied some lead, just enough to make it sink. But, by taking off the external pressure, the cork will bring the lead up to the surface.

E. Is that because, when the pressure is taken off, the substance of the cork expands, and becomes specifically lighter than it was before?

F. It is. This experiment is varied by using a bladder, in which is tied up a very small quantity of air, and sunk in water; for when the external pressure is removed, the spring of air within the bladder will expand it, make it specifically lighter than water, and bring it to the surface.

The next experiment shows that the ascent of smoke and vapours depends on the air. I will blow out this candle, and put it under the receiver; the smoke now rises to the top, but as soon as the air is exhausted to a certain degree, the smoke descends, like all other heavy bodies.

C. Do smoke and vapours rise because they are lighter than the surrounding air?

F. That is the reason. Sometimes you see smoke from a chimney rise quite vertically in a long column; the air then is very heavy; at other times you may see it descend, which is a

proof that the density of the atmosphere is very much diminished, and is, in fact, less than that of the smoke. And at all times smoke can ascend no higher than where it meets with air of a density equal to itself, and there it will spread about like a cloud.

C. Do balloons rise on a similar principle?

F. Yes; a balloon is merely a large bag of gas. The mass of air displaced by the balloon is heavier than the balloon and all its appendages, so that the latter rises in it. A Montgolfier is a bag of air rarefied, and so made lighter by a fire or a flame of spirit.

C. I once noticed Mr. Green make an ascent. I observed that when the balloon was full, he took the neck away from the gas-pipe, and tied it with his handkerchief. I was sure he had something in view, for he was so very careful in tying the handkerchief, and I watched him?

E. And what did he do?

C. To my astonishment, when everything was ready, he let go the rope which held down the balloon, and at the same moment he actually pulled away the handkerchief and opened the neck of the balloon, so that the gas could all escape. I should have thought it was an accident, if I had not seen him wave the same handkerchief. What could he mean by this, papa; first to fill his balloon, and then, when I should have thought he most needed the gas, to let it out?

F. He fills his balloon because the public, after paying their shillings, would not like to see a half-filled bag ascend. But, as he rises from the earth, the pressure of the atmosphere upon the balloon gradually decreases; because part of the column of air is left below him. This being the case, the confined gas expands; and if he were not to open the neck, the balloon would very soon be burst open, just as the square bottle (fig. 15.) burst.

The reason of his opening the *neck* of the balloon is because in the process of ascending the gas can more easily escape from below; but if he wishes to descend, he pulls a cord and opens a valve at the top of the balloon, and the descending motion squeezes, as it were, the gas out. If he wished to rise again, he throws out some sand, and makes the whole machine lighter. So you see, he arrives at the earth again with a far less supply of gas than he started with.

Fig. 20. is usually called the lungs-glass. A bladder is tied close about the little pipe *a*, which is screwed into the bottle A, and at first nearly fills it. I introduce it under the receiver B, and begin to exhaust the air of the receiver, and that in the

bladder communicating with it will also be withdrawn: the elastic force of the air in the bottle A will now press the bladder to the shrivelled state represented in the figure. I will admit the air, which expands the bladder; and thus, by alternately exhausting and re-admitting the air, I show the action of the lungs in breathing. But perhaps the following experiment will give a better idea of the subject. In fig. 21., A represents the

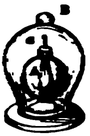


Fig. 20.

Fig. 21.

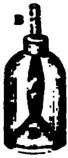


Fig. 22.

lungs, B the windpipe leading to them, which is closely fixed in the neck of the bottle, from which the air cannot escape; D is a bladder tied to the bottom, and in its distended state will, with the internal cavity of the bottle, represent the cavity of the body, which surrounds the lungs, at the moment you have taken in breath; I force up D (as in fig. 22.), and now the bladder is shrivelled by the pressure of the external air in the bottle, and represents the lungs just at the moment of expiration.

I have exactly balanced on this scale-beam a piece of lead and a piece of cork. In this state I will introduce them under the receiver, and exhaust the air.

C. The cork now seems to be heavier than the lead.

F. In air each body *lost* a weight proportional to its *bulk*; but when the air is taken away, the weight lost will be restored; but as the lead lost least, it will now regain the least; consequently the cork will preponderate with the difference of the weights restored by taking away the air.

Thus you see that *in vacuo, a pound of cork, or feathers,* would be heavier *than a pound of lead*; as I mentioned in an earlier conversation.

E. Why do bodies, when weighed in air, lose weights proportional to their bulks?

F. Because the air, being a fluid substance, tends to lift up a body immersed in it; and the larger the body, the more effect it will have upon it. Of course, it has more effect on an ounce of cork than on an ounce of lead.

CONVERSATION X.

Of the Air-gun and Sound.

F. The air-gun is an instrument, the effects of which depend on the elasticity and compression of air.

E. Is it used for the same purposes as common guns?

F. Air-guns will answer all the purposes of a musket or fowling-piece. Bullets discharged from them will kill animals at the distance of 50 or 60 yards. They make no report, and on account of the great mischief they are capable of doing, without much chance of discovery, they are deemed illegal, and are, or ought to be, found nowhere but among the apparatus of the experimental philosopher.

C. Can you show us the construction of an air-gun?

F. It was formerly a very complex machine; but now the construction of air-guns is very simple; fig. 23. is one of the most approved.

E. In appearance it is very much like a common musket, with the addition of a round ball c.

F. That ball is hollow, and contains the condensed air, which is forced into it by means of a syringe; it is then screwed to the barrel of the gun.

C. Is there fixed to the ball a valve opening inwards?

F. There is; and when the leaden bullet is rammed down, the trigger is pulled back, which forces down the hook *b* upon

Fig. 23.

the pin connected with the valve, and liberates a portion of the condensed air; this, rushing through a hole in the lock into the barrel, will impel the bullet to a great distance.

E. Does not all the air escape at once?

F. No; if the gun be well made, the copper ball will contain enough for 15 or 20 separate charges; so that one of these is capable of doing much more execution in a given time than a common fowling-piece.

C. Does not the strength of the charges diminish each time?

F. Certainly; because the condensation becomes less upon the loss of every portion of air; so that after a few discharges the

bullet will be projected only a short distance. To remedy this inconvenience, you might carry a spare ball or two ready filled with condensed air in your pocket, to screw on when the other was nearly exhausted. Formerly, this kind of instrument was attached to gentlemen's walking-sticks.

A still more formidable instrument is called the *Magazine wind-gun*. In this, there is a magazine of bullets, as well as another of air; and, when it is properly charged, the bullets may be projected one after another as fast as the gun can be cocked and the pan opened. The syringe in these is fixed to the butt of the gun, by which it is easily charged, and may be kept in that state for a great while.

E. Does air never lose its elastic power?

F. It would be too much to assert that it never will; but experiments have been tried upon different portions of it, which have been found as elastic as ever after the lapse of many months, and even years.

C. What is this bell for?

F. I took it out to show you that air is the medium by which, in general, sound is communicated. I will place it under the receiver of the air-pump, and exhaust the air. Now observe the clapper of the bell while I shake the apparatus.

E. I see clearly that the clapper strikes the side of the bell, but I do not hear any ringing.

F. Turn the cock and admit the air; now you hear the sound plainly enough: and if I use the syringe and a different kind of glass, so as to condense the air, the sound will be very much increased. Dr. Desaguliers says, that in air that is twice as dense as common air, he could hear the sound of a bell at double the distance.

C. Is it on account of the different densities of the atmosphere that we hear St. Paul's clock so much plainer at one time than another?

F. Undoubtedly the different degrees of density in the atmosphere will occasion some difference; but the principal cause depends on the quarter from which the wind blows; for as the direction of that is towards or opposite to our house, we hear the clock better or worse.

E. Does it not require great strength to condense air?

F. That depends much on the size of the piston belonging to the syringe; for the force required increases in proportion to the square of the diameter of the piston.

Suppose the area of the base of the piston is one inch, and you have already forced so much air into the vessel that its density is double that of common air, the resistance opposed to

you will be equal to 15 pounds; but if you would have it ten times as dense, the resistance will be equal to 150 pounds.

C. That would be more than I could manage.

F. Well, then, you must take a syringe, the area of whose piston is only half an inch; and in that case the resistance would be equal to only the fourth part of 150 pounds, because the square of $\frac{1}{2}$ is equal to $\frac{1}{4}$.*

C. You spoke of liquid carbonic acid producing *cold* by expanding, does air when condensed produce *heat?*

F. Yes; and there is a kind of syringe made with a tight piston, and a piece of German tinder inside, and by driving down the piston by a smart blow the tinder is inflamed.

E. You said that the air was *generally* the medium by which sound is conveyed to our ears; is it not always so?

F. Air is always a good conductor of sound, but water is a still better. Two stones being struck together under water, the sound may be heard at a greater distance by an ear placed under water in the same river, than it can through the air. In calm weather, a whisper may be heard across the Thames.

The slightest scratch of a pin, at one end of a long piece of timber, may be heard by an ear applied near the other end, though it could not be heard at half the distance through the air.

The earth is not a bad conductor of sound: it is said that, by applying the ear to the ground, the trampling of horses may be heard much sooner than it could through the medium of the air. Recourse has sometimes been had to this mode of learning the approach of an hostile army.

Take a long strip of flannel, and in the middle tie a common poker, which answers as well as anything, leaving the ends at liberty: these ends must be rolled round the end of the first finger of each hand, and then stopping the ears with the ends of these fingers, strike the poker, thus suspended, against any body, as the edge of a steel fender; the depth of the tone which the stroke will return is amazing; that made by the largest church-bell is not to be compared with it. Thus it appears that flannel is an excellent conductor of sound.

CONVERSATION XI.

Of Sound.

F. We will devote this Conversation to the consideration of sound; which in so far as it is connected with vibrations pro-

* The square of any number being the number multiplied into itself, $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

duced in the air, may come under the head of Pneumatics, although it really forms a distinct branch of science termed Acoustics.

C. Is air the cause of sound?

F. Not the cause; but commonly the conductor of sound.

E. Is not thunder produced by the air?

F. All we know of thunder is that electric force passes between two points, and disturbs the intervening molecules of air: they are then thrown into a sudden and violent state of vibration; and vibration and sound are pretty nearly the same thing. The lightning flash takes a long journey in an incredibly short space of time; and it produces this vibration along its whole course; but sound, as we shall presently see, takes some time to travel to our ear, so that we get a continuous rolling until the last audible wave of sound has arrived.

C. Can the report of a large cannon be called a miniature imitation? I remember being once in a room at the distance of but a few paces from the Tower guns when they were fired, and the noise was very great.

F. This was because you were near: gunpowder, when inflamed in a *vacuum*, makes no more sound than the bell in like circumstances.

Mr. Cotes mentions a very curious experiment which was contrived to show that sound cannot penetrate through a vacuum. A strong receiver, filled with common atmospheric air, in which a bell was suspended, was screwed down to a brass plate so tight that no air could escape, and this was included in a much larger receiver. When the air between the two receivers was exhausted, the sound of the bell could not be heard.

E. Could it be heard before the air was taken away?

F. Yes; and also the moment it was re-admitted.

C. What is the reason that some bodies sound so much better than others? Bell-metal is more musical than copper or brass, and these sound much better than many other substances.

F. All sonorous bodies are elastic, and their parts by percussion can be made to vibrate; and as long as the vibrations continue, corresponding vibrations are communicated to the air, and these produce sound. Musical chords and bells are instances that will illustrate this.

E. The vibrations of the bell are not visible; and musical chords will vibrate after their sound has vanished.

F. If light particles of dust be on the outside of a bell when it is struck, you will, by their motion, have no doubt but that the particles of the metal move too, though not sufficiently to be visible to the naked eye. If you take a plate of glass and

sprinkle on it a little fine sand, and then hold it at one corner by a pair of pliers, and pass a violin-bow along one of the sides, you will see the sand arrange itself into a uniform figure: if you apply the bow to one corner, the figure will be varied; and by this means you may produce some beautiful arrangements of the sand, and almost say that you *see* sound.

C. Is it known how far sound can be heard?

F. We are assured upon good authority, that the unassisted human voice has been heard in the stillness of night at the distance of 10 or 12 miles; namely, from New to Old Gibraltar. And in the famous sea-fight between the English and Dutch, in 1672, the sound of cannon was heard at the distance of 200 miles from the place of action. In both these cases the sound passed over water; and it is well known that sound may be always conveyed much farther along a smooth than an uneven surface.

Experiments have been instituted to ascertain how much water, as a conductor of sound, was better than land; and a person was heard to read very distinctly at the distance of 140 feet on the Thames, and on land he could not be heard farther than 76 feet.

E. Might not there be interruptions in the latter case?

F. No noise whatever intervened by land, but on the Thames there was some occasioned by the flowing of the water.

C. As we were walking last summer towards Hampstead, we saw a party of soldiers firing at a mark near Chalk Farm, and you desired Emma and me to take notice that the report was heard after we saw the flash.

F. My intention was that you should know, from actual experiment, that sound is not conveyed instantaneously, but takes a certain time to travel over a given space.

When you stood close to the place, did you not observe the smoke and hear the report at the same instant?

E. Yes, we did.

F. Then you are satisfied that the light of the flash, and the report, are always produced together. The former comes to the eye with the velocity of light, the latter reaches the ear with the velocity with which sound travels; if, then, light travels faster than sound, you will, at any considerable distance from a gun that is fired, see the flash before you hear the report. Do you know with what velocity light travels?

C. At the rate of 12 millions of miles in a minute.*

F. With regard then to several hundred yards, or even a few miles, the motion of light may be considered as instantaneous,

* See Astronomy, Conversation XXVI.

E. This I understand, because 10 miles is as nothing when compared with 12 millions.

F. Now sound travels only at the rate of about 13 miles in a minute. Sir John Herschel shows that at the temperature of 62°, sound travels at the rate of 1125 feet per second; and that for every reduction of one degree in temperature, it gains 1·14 feet per second. The average velocity, therefore, is 9000 feet, or 3000 yards, in 8 seconds. Therefore, as time is easily divisible into seconds, the progressive motion of sound is readily marked by means of a stop-watch.

C. Is it certain that sounds of all kinds travel at this rate?

F. A great variety of experiments have been made on the subject, and it seems now generally agreed that all sound travels with a uniform velocity.

E. Then with a stop-watch you could have told how far we were from the firing when we first saw it.

F. Most easily; for I should have counted the number of seconds that elapsed between the flash and the report, and then have multiplied 1125 by the number, and I should have had the exact distance in feet between us and the gun.

C. Has this knowledge been applied to any practical purpose?

F. It has frequently been used at sea, by night, to know the distance of a ship that has fired her watch-guns. Suppose you were in a vessel, and saw the flash of a gun, and between that and the report 24 seconds elapsed, what would be the distance of one vessel from another?

E. I should multiply 1125 by 24, and then bring the product into yards, which in this instance is equal to something more than 9000 yards.

F. By counting the number of seconds elapsed between the flash of lightning and the clap of thunder, you may ascertain how far distant you are from the storm.

C. I should like to have a stop-watch to be able to calculate this for myself.

F. As it will probably be some time before you become possessed of such an expensive instrument, I will tell you of something which you have always about you, and which will answer the purpose.

E. What is that, papa?

F. The pulse at your wrist, which, in healthy people, generally beats about 75 times in a minute*: in the same space of time sound flies 1125 ft. $\times$ 60 $=$ 67,500 ft.; divide this by 75, and you get 900 feet, as the distance travelled over during each pulsation.

* In children the pulse is more rapid.

E. If I see a flash of lightning, and between that and the thunder I count at my wrist 36 or 60 pulsations, I say the distance in one case is equal to $36 \times 900 = 32{,}400$ feet, or 10,800 yards; and in the other to $60 \times 900 = 54{,}000$ feet, or 18,000 yards.

F. You are right; and this method will, for the present, be sufficiently accurate for all your purposes.

C. The information you have now given us is highly interesting; and I doubt not but that my sister and I shall meet with many opportunities of putting it in practice.

CONVERSATION XII.

Of the Speaking Trumpet.

C. I have been thinking about the nature of sound, and am anxious to ask what it is.

F. It would be but of little use to give you a definition of sound; but I will endeavour to illustrate the subject. You saw just now that when you vibrated the glass plate, and the waves met with sand, the latter assumed a certain regular arrangement; when the same waves touch the ear, they produce certain sensations, which are carried to our brain, and which we call sound. If there were no ears there would be no sound. Uniform vibrations produce *sound;* irregular vibrations produce *noise.*

E. Is it such a wave as we see in the pond when it is ruffled by the wind?

F. Rather such a one as is produced by throwing a pebble into still water.

C. I have often observed this; the surface of the water forms itself into circular waves.

F. It is probable that the tremulous motion of the parts of a sonorous body communicate undulations to the air in a similar manner. Two obvious circumstances must strike every observer with regard to the undulations in water. 1st. The waves, the farther they proceed from the striking body, become less and less, till, if the water be of a sufficient magnitude, they become invisible, and die away. The same thing takes place with regard to sound; the farther a person is from the sounding body, the less plainly it is heard, till at length the distance is too great for it to be audible. 2dly. The waves on the water are not propagated instantaneously, but are formed one after another in a given space of time. This, from what we have already shown, appears to be the manner in which sound is propagated.

C. I have noticed that, when I throw two stones into a pond, the waves in some parts interfere, and produce still water. Now, can two sounds produce silence?

F. Yes: providing the waves are so circumstanced; a case in point is that peculiar thrilling which you hear occasionally, aye, and feel too, in the church organ.

E. Is sound the effect which is produced on the ear by the undulations of the air?

F. It is; and according as these waves are stronger or weaker, the impression, and consequently the sensation, is greater or less. If sound be impeded in its progress by a body that has a hole in it, the waves pass through the hole, and then diverge on the other side as from a centre: the vibrations of the substance of the sides of a tube, as well as the shape of the mouth, tend to augment the sound. Upon this principle the *speaking-trumpet* is constructed.

C. What is that, sir?

F. It is a long tube, used for the purpose of making the voice heard at a considerable distance: the length of the tube is from 6 to 12 or 15 feet; it is straight throughout, having at one end a large aperture, and the other terminates in a proper shape and size to receive the lips of the speaker.

E. Are these instruments much in use?

F. It is believed that they were more used formerly than now: they are certainly of great antiquity. Alexander the Great made use of such a contrivance to communicate his orders to the army; by means of which, it is asserted, he could make himself perfectly understood at the distance of 10 or 12 miles. Stentor is celebrated by Homer as one who could call louder than fifty men. From Stentor, the speaking-trumpet has been called the Stentorophonic tube.

C. Perhaps Stentor was employed in the army for the purpose of communicating the orders of the general, and he might make use of a trumpet for the purpose, and that is what is meant by brazen lungs.

F. That is not an improbable conjecture. Well, besides speaking-trumpets, there are others contrived for assisting the hearing of deaf persons, which differ but little from the speaking-trumpet.

If A and B represent two trumpets, placed in an exact line at the distance of 40 feet or more from one another, the smallest whisper at *a* would be distinctly heard at *b*; so that by a contrivance to conceal the trumpets, many of those speaking figures are constructed which are frequently exhibited in the metropolis and other large towns.

[Fig. 24.]

E. I see how it may be done; there must be two sets of trumpets, the one connected with the ear of the image into which the spectator whispers, and which conveys the sound to a person in another room, who, by tubes connected with the mouth of the image, returns the answer.

C. I saw the original invisible girl, which has been deposited by Mr. Foy in the Polytechnic Institution for the express purpose of showing the principles of natural philosophy that were employed in the deception. A hollow ball, about a foot in diameter, is suspended by ribands; it hangs free, and has four trumpet mouths; the wonder was that, on asking a question of this ball, a female voice answered from its interior. The fact was, the trumpet-mouths *faced* the ends of a pipe concealed in the frame; the pipe led to an adjoining room where the female was concealed.

CONVERSATION XIII.

Of the Echo.

F. Let us turn our attention to another curious subject relating to sound, and which depends on the air; I mean the echo.

E. I have often been delighted to hear my own words repeated, and I once asked Charles how it happened that, if I stood in a particular spot in the garden, and shouted aloud, my words were distinctly repeated; whereas, if I moved a few yards nearer to the wall, I had no answer. He told me that he knew nothing more than this, that in a part of Ovid's Metamorphoses Echo is represented as having been a nymph of the woods, but that, pining away in love, her voice was all that was left of her.

F. I apprehend this gave your sister but little satisfaction respecting the cause of the echo. I will endeavour to explain the subject. When you throw a pebble into a small pool of water, what happens to the waves when they reach the margin?

C. They are thrown back again.

F. The same happens with regard to the undulations in the air, which are the cause of sound. They strike against any surface fitted for the purpose, as the side of a house, a brick wall, a hill, or even against trees, and are reflected or beat back again; this is the cause of an echo.

E. I wonder then that we do not hear echoes more frequently.

F. There must be several concurring circumstances before an echo can be produced. For an echo to be heard, the ear must be in the *line of reflection.*

C. I do not know what you mean by the line of reflection.

F. I cannot always avoid using terms that have not been previously explained. This is an instance. I will, however, explain what is meant by the line of incidence and the line of reflection. When you come to Optics, these subjects will be made familiar to you. You can play at marbles?

C. Yes, and so can Emma.

F. Suppose you were to shoot a marble against the wainscot, what would happen?

C. That depends on the direction in which I shoot it: if I stand directly opposite to the wainscot, the marble will, if I shoot it strong enough, return to my hand.

F. The line which the marble describes in going to the wall is called the *line of incidence*, and that which it makes in returning is *the line of reflection.*

E. But they are both the same.

F. In this particular instance they are so: but suppose you shoot obliquely or sideways against the board, will the marble return to the hand?

C. O no! it will fly off sideways in a contrary direction.

F. There the line it describes *before the stroke*, or the line of incidence, is different from that of reflection, which it makes *after the stroke.* I will give you another instance; if you stand before the looking-glass you see yourself, because the rays of light flow from you, and are reflected back again in the same line. But let Emma stand on one side of the room, and you on the other side: you both see the glass at the upper end of the room?

E. Yes, and I see Charles in it too.

C. I see Emma, but I do not see myself.

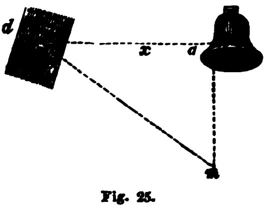


Fig. 25.

F. This happens just like the marble which you shot sidewise. The rays flow from Emma obliquely on the glass, upon which they strike and fly off in a contrary direction, and by them you see her. I will apply this to sound. If a bell *a* be struck, and the undulation of the air air strike the wall *c d* in a perpendicular direction, they will be reflected back in the same line; and if a

person were properly situated between *a* and *c*, as at *x*, he would hear the sound of the bell by means of the undulations as they went to the wall, and he would hear it again as they came back, which would be the echo of the first sound.

E. I now understand the distinction between the direct sound and the echo.

F. If the undulations strike the wall obliquely, they will, like the marble against the wainscot, or the rays of light against the glass, fly off again obliquely on the other side, in a reflected line, as *c m;* now if there be a hill or other obstacle between the bell and the place *m* where a person happens to be standing, he will not hear the direct sound of the bell, but only the echo of it, and to him the sound will come along the line *c m*.

C. I have heard of places where the sound is repeated several times.

F. This happens where there are a number of walls, rocks, &c., which reflect the sound from one to the other; and where a person happens to stand in such a situation as to intercept all the lines of reflection. These are called tautological or babbling echoes.

There can be no echo unless the direct and reflected sounds follow one another at a sufficient interval of time; for if the latter arrive at the ear before the impression of the direct sound ceases, the sound will not be double, but only rendered more intense.

E. Is there any rule by which the time may be ascertained?

F. You must be so placed in regard to the reflecting surface, that the original sound shall have died away before the vibration can be reflected back. If it takes one second to die away, you must allow it somewhat more than 1142 ft; and must therefore be above half that distance, or 571 feet, from the reflecting surface; if it takes two seconds, you must be more than $\frac{571}{2}$ on $285\frac{1}{2}$ ft.; if 3 seconds, more than $\frac{571}{3}$ or $190\frac{1}{3}$ ft. distant, and so on: and if several syllables are repeated before the echo commences, you may fairly calculate how far distant the reflecting surface is, from the time that elapses between your commencing and the echo commencing.

CONVERSATION XIV.

Of the Echo.

F. I will now name to you some of the most celebrated echoes. At Rossneath, near Glasgow, there is an echo that repeats a tune played with a trumpet three times completely and

distinctly. Near Rome there was one that repeated what a person said five times. At Brussels, there is an echo that answers 15 times. At Thornbury Castle, Gloucestershire, an echo repeats 10 or 11 times very distinctly. Between Coblentz and Bingen an echo is celebrated as different from most others. In common echoes the repetition is not heard till some time after hearing the words spoken or notes sung; in this the person who speaks or sings is scarcely heard, but the repetition is perceived very clearly, and in surprising varieties. The echo in some cases appears to be approaching, in others receding; sometimes it is heard distinctly, at others scarcely at all; one person hears only one voice, while another hears several. And, to mention but one more instance, in Italy, near Milan, the sound of a pistol is returned 56 times. The ingenious Mr. Derham applied the echo to measuring inaccessible distances.

C. How did he do this?

F. Standing on the banks of the Thames, opposite to Woolwich, be observed the echo of a single sound was reflected from the houses in three seconds; consequently in that time it had travelled 3426 feet, the half of which, or 1713 feet, was the breadth of the river in that particular place.

Did you ever hear of the Whispering Gallery in the dome of St. Paul's Church?

E. Yes; and you promised to take us to visit it some time.

F. And I will perform my promise. In the meanwhile it may be proper to inform you, that the circumstance that attracts every person's attention is, that the smallest whisper made against the wall on one side of the gallery is distinctly heard on the other side.

C. Is this effect produced on the principle of echo?

F. No; it is merely reflection of sound. The vaulted roof is of such a shape, that a line drawn from the hearer, and another from the speaker to any spot make the same angle; and consequently *every spot* sends a wave of sound to the hearer, and he thus hears a sound of a magnified intensity.

E. I have heard of the echo of Westminster Bridge, papa?

F. This is somewhat of a similar nature. If you place yourself in what is called the focus of one of the stone recesses, and speak toward the wall, while your brother stands in the opposite recess with his face to the wall, he will hear what you say, in spite of the noise of the carriages. The sound from your lips is reflected in *straight* lines from the wall, passes across the road in *straight* lines, touches the wall of the other recess, and is reflected back to your brother's ear in a focus.

C. Is there a material difference in the conveyance of sound, whether the medium be rough or smooth?

F. The difference is very great. Still water is, perhaps, the best conductor of sound. The echo which I mentioned in the neighbourhood of Milan depends much on the water over which the villa stands. Dr. Hutton, in his Mathematical Dictionary, gives the following instance, as a proof that moisture has a considerable effect upon sound. A house in Lambeth Marsh is very damp during winter, when it yields an echo, which abates as soon as it becomes dry in summer. To increase the sound in a theatre at Rome, a canal of water was carried under the floor, which caused a great difference.

Next to water, stone is reckoned a good conductor of sound, though the tone is rough and disagreeable; a well-made brick wall has been known to convey a whisper to the distance of 200 feet nearly. Wood is sonorous, and produces the most agreeable tone, and is therefore the most proper substance for musical instruments. Of these we shall say a word or two before we quit the subject of sound.

E. All wind instruments, as flutes, trumpets, &c., must depend on the air; but do stringed instruments?

F. They all depend on the vibrations which they make in the surrounding air. I will illustrate what I have to say by means of the Æolian harp.

If a cord eight or ten yards long be stretched very tightly between two points, and then struck with a stick, the whole string will not vibrate, but there will be several still places in it, which are called nodes, between which the cord will move. Now, the air acts upon the strings of the Æolian harp in the same manner as the stroke of the stick upon the long cord just mentioned. Hence every string in an Æolian harp, though all are in unison, becomes capable of several sounds, from which arises the wild harmony of that instrument.

The undulations of the air, caused by the quick vibrations of a string, are well illustrated by a sort of mechanical sympathy that exists among accordant sounds. If two strings on different instruments are tuned in unison, and one be struck, the other will reply, though they be several feet distant from one another.

E. How is this accounted for?

F. The waves made by the first string being of the same kind as would be made by the second if struck, those waves give a mechanical stroke to the second string, and produce its sound.

C. If all the strings on the Æolian harp are set to the same note, will they all vibrate by striking only one?

F. They will; but the fact is well illustrated in this method: bend little bits of paper over each string, and then strike one sufficiently to shake off its paper, and you will see the others will fall from their strings.

E. Will not this happen if the strings are not in unison?

F. Try for yourself. Alter the notes of all the strings but two, and place the papers on again; vibrate that string which is in unison with another.

E. The papers on those are shaken off; but the others remain.

F. A wet finger pressed round the edge of a thin drinking-glass will produce its key. If the glass be struck so as to produce its pitch, and an unison to that pitch be strongly excited on a violoncello, the glass will be set in motion, and if near the edge of the table, will be liable to be shaken off.

On the same principle the musical glasses are constructed, which are said to produce sweeter tones than can be had from any other instrument, and that may be swelled and softened at pleasure by different pressures of the finger.

The fundamental facts on which the whole depends are these. The nature of the tone, as to *gravity* or *acuteness*, depends altogether upon the number of vibrations made in a given time. the *sweetness* of the tone depends upon the vibrating substance of the instrument, and more or less, also, upon the shape or symmetry of the instrument. Any substance whatever, when it makes 118 vibrations in a second, will yield a tone which is in unison with the lowest C upon our violoncellos. If any sonorous body give twice this number, or 236 vibrations in a second, the tone will be C, an octave higher. If it be made to give 472 vibrations in a second, the sound will be an octave higher still. If the vibrations in a second were $\frac{3}{2}$ of 118, or 177, the sound yielded would be G, a fifth above the first C; 354, 708, 1416, &c., would give a series of G's successively, each an octave above the preceding. And, in like manner, intermediate numbers of vibrations easily computed would yield all the intermediate tones and semitones in an octave.

CONVERSATION XV.

Of the Winds.

F. You know, my dear children, what the wind is?

C. You told us, a few days ago, that you should prove it was only the air in motion.

F. I can show you in miniature, that air in motion will produce effects similar to those produced by a violent wind.

I place this little mill under the receiver of the air-pump in such a manner that the air, when re-entering, may catch the vanes. I will exhaust the air; now observe what happens when the stop-cock is opened.

E. The vanes turn round with an incredible velocity; much swifter than ever I saw the vanes of a real windmill. But what puts the air in motion, so as to cause the wind? I mean in the actual case of the wind.

F. There are, probably, many conspiring causes to produce the effect. The principal one seems to be heat communicated by the sun.

C. Does heat produce wind?

F. Heat, you know, expands all bodies; consequently it rarefies the air, and make it lighter. But you have seen that the lighter fluids ascend, and thereby leave a partial vacuum, towards which the surrounding heavier air presses, with a greater or less quantity of motion, according to the degree of rarefaction or of heat which produces it. The air of this room, by means of the fire, is much warmer than that in the passage.

E. Has that in the passage a tendency into the parlour?

F. Take this lighted wax taper and hold it at the bottom of the door.

C. The wind blows the flame violently into the room.

F. Hold it now at the top of the door.

C. The flame rushes outwards there.

F. This simple experiment deserves your attention. The heat of the room rarefies the air, and the lighter particles ascending, a partial vacuum is made at the lower part of the room; to supply the deficiency, the dense outward air rushes in, while the lighter particles, as they ascend, produce a current at the top of the door out of the room. If you hold the taper about the middle space, between the bottom and top, you will find a part in which the flame is perfectly still, having no tendency either inwards or outwards.

The *smoke-jack*, so common in the chimneys of large kitchens, consists of a set of vanes, something like those of a windmill or ventilator, fixed to wheelwork, which are put in motion by the current of air up the chimney, produced by the heat of the fire, and of course the force of the jack depends on the strength of the fire, and *not* upon the quantity of smoke, as the name of the machine would lead you to suppose.

E. Would you define the wind as a current of air?

F. That is a very proper definition; and its direction is denominated from that quarter from which it blows.

C. When the wind blows from the north or south, do you

say it is in the former case a north-wind, and in the latter a south wind?

F. We do. The winds are generally considered as of three kinds independently of the names which they take from the points of the compass from which they blow. These are the *constant*, or those which always blow in the same direction; the *periodical*, or those which blow six months in one direction, and six in a contrary direction; and the *variable*, which appear to be subject to no general rules.

E. Is there any place where the wind always blows in one direction only?

F. This happens to a very large part of the earth; to all that extensive tract that lies between 28 to 30 degrees north and south of the equator.

C. What is the cause of this?

F. The equatorial regions are the hottest in the world; and hence to the poles, the average temperature is less and less. The heated air of the tropics rises to the upper regions and passes off towards the poles, while the air of the lower strata passes towards the equator. Thus far it would produce a constant north wind on the north of the equator, and a south wind on the south side. But, as the earth rotates from west to east, and with its own velocity, which these winds have not acquired, they are as it were left behind; and the result is a north-east wind on the north of the equator, and a south-east on the south; and at the equator the result is a constant east-wind; the north and the south portions neutralising each other and leaving only the east. These winds are called *trade-winds*, and have more or less north and south in them according as they are more or less distant from the equator.

E. In what part of the globe do the *periodical* winds prevail?

F. They prevail in several parts of the Eastern and Southern Oceans, and evidently depend on the sun; for when the apparent motion of that body is north of the equator, that is, from the end of March to the same period in September, the wind sets in from the south-west; and the remainder of the year, while the sun is south of the equator, the wind blows from the north-east. These are called the monsoons, or shifting trade-winds, and are of considerable importance to those who make voyages to the East Indies.

C. Do these changes take place suddenly?

F. No; some days before and after the change there are calms, variable winds, and frequently the most violent storms.

On the greater part of the coasts situated between the tropics, the wind blows towards the shore in the daytime, and

towards the sea by night. These winds are called sea and land breezes; they are affected by mountains, the course of rivers, tide, &c.

E. Is it the heat of the sun by day that rarefies the air over the land, and thus causes the wind?

F. It is; the following easy experiment will illustrate the subject.

In the middle of a large dish of cold water put a water-plate filled with hot water: the former represents the ocean, the latter the land, rarefying the air over it. Hold a lighted candle over the cold water, and blow it out; the smoke, you see, moves towards the plate. Reverse the experiment, by filling the outer vessel with warm water, and the plate with cold, the smoke will move from the plate to the dish.

C. In this country there is no regularity in the direction of the winds; sometimes the easterly winds prevail for several days together, at other times I have noticed the wind blowing from all quarters of the compass two or three times in the same day.

F. The variableness of the wind in this island depends probably on a variety of causes; for whatever destroys the equilibrium in the atmosphere, produces a greater or less current of wind towards the place where the rarefaction exists.

C. Is there any method of ascertaining the velocity of the wind?

F. Yes: several machines have been invented for the purpose. Dr. Derham, by means of the flight of small downy feathers, contrived to measure the velocity of the great storm which happened in the year 1705, and he found that the wind moved 33 feet in half a second, that is, at the rate of 45 miles per hour; and it has been proved that the force of such a wind is equal to the perpendicular force of 10 pounds avoirdupois weight on every square foot. Now if you consider the surface which a large tree, with all its branches and leaves, presents to the wind, and the great length of lever at which the forces act, you will not be surprised that, in great storms, some of them should be torn up by the roots.

E. Is the velocity of 45 miles an hour supposed to be the greatest velocity of the wind?

F. Dr. Derham thought the greatest velocity to be about 60 miles per hour; but we have no doubt that the velocity is often considerably greater. Lunardi and Garnerin were carried in their respective balloons at the rate of 70 miles an hour, and not in the time of a violent storm. We have tables calculated

to show the *force* of the wind at all velocities from 1 to 100 miles per hour.

C. Does the *force* bear any general proportion to the velocity?

F. Yes, it does; the force increases as the *square* of the velocity.

E. Do you mean, that if on a piece of board, exposed to a given wind, there is a pressure equal to 1 pound, and the same board be exposed to another wind of *double* velocity, the pressure will be in this case 4 times greater than it was before?

F. That is the rule. The following short table, selected from a larger one out of Dr. Hutton's Dictionary, will fix the rule and facts in your memory.

TABLE.

Velocity of the Wind, in Miles per Hour.	Perpendicular Force on 1 Square Foot in Pounds Avoirdupois.	Common Appellations of the Wind.
5	·123	Gentle pleasant wind.
10	·492	Brisk gale.
20	1·968	Very brisk.
40	7·872	High wind.
80	31·488	A hurricane.

E. Did we not see an instrument for measuring wind at the Polytechnic, papa?

F. Yes, dear; it was Osler's *anemometer:* it not only measures the pressure and direction of the wind, but it writes them down in pencil. The vane on the top of the building presents a square plate to the wind; this plate is mounted on certain springs, which are more or less pressed upon, as the wind is higher or not. The rate of pressure is communicated to a rod, which passes down in the interior of the building, and carries a pencil point: this point varies its position, according as the pressure varies; and a sheet of paper divided into hours passes by means of clockwork beneath the pencil, and receives the record. A similar pencil point, connected with the vane, registers the change of wind.

C. But that is surely not Osler's anemometer on the Royal Exchange?

F. No; it is Whewell's: it registers the velocity of the wind; you observe the fly rotating; of course it moves faster as the wind is higher, and the registered result varies accordingly.

Note.—Mr. Brice discovered, from observations on the clouds,

or their shadows moving on the surface of the earth, that the velocity of wind in a storm was nearly 63 miles in an hour, 21 miles in a fresh gale, and nearly 10 miles in a breeze. These, however, are not very accurate estimates.

CONVERSATION XVI.

Of the Steam-Engine.

C. To whom is the world indebted for the steam-engine?

F. It is difficult, if not impossible, to ascertain who was the inventor. The Marquis of Worcester described the principle in a small work, entitled "A Century of Inventions," which was published in the year 1663, and was reprinted a few years since in the second volume of Dr. Gregory's "Mechanics."

E. Did the marquis construct one of these engines?

F. No; the invention seems to have been neglected for several years, when Captain Thomas Savery, after a variety of experiments, brought it to some degree of perfection, by which he was able to raise water, in small quantities, to a moderate height.

C. Did he take the invention from the Marquis of Worcester's book?

F. Dr. Desaguliers, who, in the middle of the last century, entered at large into the discussion, maintains that Captain Savery was wholly indebted to the marquis, and, to conceal the piracy, he charges him with having purchased all the books which contained the discovery, and burned them. Captain Savery, however, declared that he was led to the discovery by the following accident: "Having drunk a flask of Florence wine at a tavern, and thrown the flask on the fire, he perceived that the few drops in it were converted into steam; this induced him to snatch it from the fire, and plunge its neck into a basin of water, which, by the atmospheric pressure, was driven quickly into the bottle."

E. This was something like an experiment which I have often seen at the tea-table. If I pour half a cup of water into the saucer, then hold a piece of lighted paper in the cup a few seconds, and when the cup is pretty warm, plunge it with the mouth downwards into the saucer, the water almost instantly disappears.

F. In both cases the principle is exactly the same: the heat of the burning paper converts the water that hung about the cup into steam; but steam, being much lighter than air, expels the air from the cup, which being plunged into the water, the steam is quickly condensed, and a partial vacuum is made in the

cup; consequently the pressure of the atmosphere upon the water in the saucer forces it into the cup, just in the same manner as the water follows the vacuum made in the pump.

C. Is steam, then, used for the purpose of making a vacuum, instead of a piston?

F. It is; and I will endeavour to give you a general explanation of Mr. Watt's engines, without entering into all the minutiæ of the several parts.

A is a section of the boiler, about half full of water, standing over a fire: B is the steam-pipe which conveys the steam from the boiler to the cylinder C, in which the piston D, made air-tight, works up and down; *a* and *c* are the steam-valves, through which

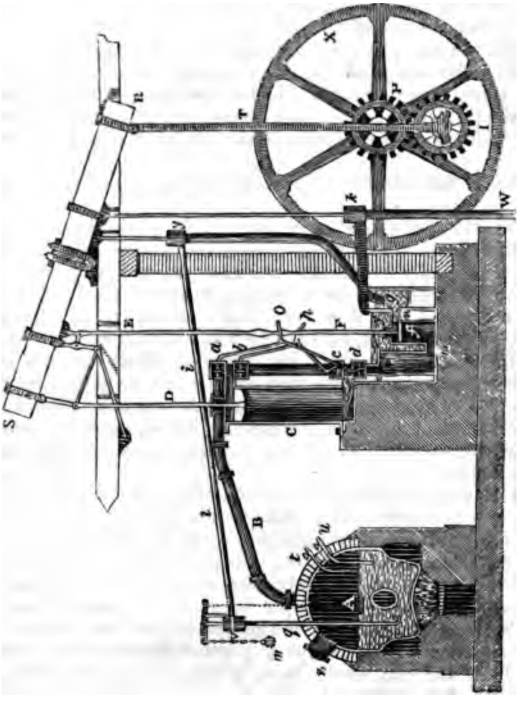


Fig. 23.

the steam enters into the cylinder; it is admitted through *a* when it is to force the piston downwards, and through *e* when it presses it upwards: *b* and *d* are the eduction valves, through which the steam passes from the cylinder into the condenser *e*, which is a separate vessel placed in a cistern of cold water, and which has a jet of cold water continually playing up the inside of it: *f* is the air-pump, which extracts the air and water from the condenser It is worked by the great beam or lever R S, and the water taken from the condenser, and thrown into the hot well *g*, is pumped up again by means of the pump *y*, and carried back into the boiler by the pipe *i i*: *k* is another pump, likewise worked by the engine itself, which supplies the cistern, in which the condenser is fixed with water.

C. Are all three pumps, as well as the piston, worked by the action of the great beam?

F. They are: and you see the piston-rod is fastened to the beam by inflexible bars: but that the stroke might be perpendicular, Mr. Watt invented the machinery called the parallel joint, the construction of which will be easily understood from the figure.

E. How are the valves opened and shut?

F. Long levers *o* and *p* are attached to them, which are moved up and down by the piston-rod of the air-pump E F. In order to communicate a rotatory motion to any machinery by the motions of the beam, Mr. Watt made use of a large fly-wheel X, on the axis of which is a small concentric toothed wheel H; a similar toothed wheel I is fastened to a rod T coming from the end of the beam, so that it cannot turn on its axis, but must rise and fall with the motion of the great beam.

A bar of iron connects the centres of the two small toothed wheels; when, therefore, the beam raises the wheel I, it must move round the circumference of the wheel H, and with it turn the fly-wheel X; which will make two revolutions while the wheel I goes round it once. These are called the sun and planet wheels; H, like the sun, turns only on its axis, while I revolves about it as the planets revolve round the sun. In modern engines, cranks are used in place of these toothed-wheels.

If to the centre of the fly-wheel any machinery were fixed, the motion of the great beam R S would keep it in constant work.

C. Will you describe the operation of the engine?

F. Suppose the piston at the top of the cylinder, as it is represented in the plate, and the lower part of the cylinder filled with steam. By means of the pump-rod E F, the steam valve *a* and the eduction valve *d* will be opened together, the branches

from them being connected at *o*. There being now a communication at *d* between the cylinder and condenser, the steam is forced from the former into the latter, leaving the lowest part of the cylinder empty, while the steam from the boiler entering by the valve *a* presses upon the piston, and forces it down. As soon as the piston has arrived at the bottom, the steam valve *c* and the eduction valve *b* are opened, while those at *a* and *d* are shut; the steam, therefore, immediately rushes through the eduction valve *b* into the condenser, while the piston is forced up again by the steam which is now admitted by the valve *c*.

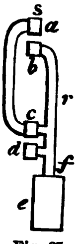


Fig. 27.

Hence, you observe, that the steam is condensed in a separate vessel, for the purpose of forming a vacuum under the piston; the force of steam is also introduced above the piston to depress it, an operation that was formerly done by the pressure of the atmosphere.

Meditate upon what we have now said, and ere long I hope we shall be able to pursue the subject.

CONVERSATION XVII.

Of the Steam-Engine. — Of the Locomotive.

C. I do not understand how the two sets of valves act, which you described yesterday as the steam and eduction valves.

F. If you look to fig. 27. there is a different view of this part of the machine, unconnected with the rest: *s* is part of the pipe which brings the steam from the boiler, and *a* represents the valve which, being opened, admits the steam into the upper part of the cylinder, forcing down the piston.

E. Is not the valve *d* opened at the same time?

F. It is; and then the steam which was under the piston is forced through into the condenser *e*. When the piston arrives at the bottom, the other pair of valves are opened, viz. *c* and *b*; through *c* the steam raises the piston, and through *b* the steam, which pressed the piston down before, is driven out into the pipe *r*, leading to the condenser; in this there is a jet of cold water constantly playing up, and thereby the steam is instantly reduced into the state of water.

C. Then the condenser *e* (see the figure at p. 258.) will soon be full of water?

F. It would, if it were not connected by the pipe *z* with the pump *f*; and every time the great beam R S is brought down,

the plunger, at the bottom of the piston-rod E F, descends to the bottom of the pump.

E. Is there a valve in the plunger?

F. Yes, which opens upwards; consequently, all the water which runs out of the condenser into the pump will escape through the valve, and be at the top of the plunger, and the valve not admitting it to return, it will, by the ascent of the piston-rod into the situation shown in the plate, be driven through *n* into *g*, the cistern of hot water, from which, owing to a valve, it cannot return.

C. And I see the same motion of the great beam puts the pump *y* into action, and brings over the hot water from the cistern *g*, through the pipe *i i* into the little cistern v, which supplies the boiler.

E. If the pump *k* brings in, by the same motion, the water from the well w, do not the hot and cold water intermix?

F. No; if you look carefully in the figure, you will observe a strong partition v, which separates the one from the other. Besides, you may perceive that the hot water does not stand at so high a level as the cold, which is a sufficient proof that they do not communicate. Indeed, the operation of the engine would be greatly injured, if not wholly stopped, if the hot water communicated with the cold; as in that case the water, being at a medium heat, would be too warm to condense the steam in *e*, and too cold to be admitted into the boiler without checking the production of the steam.

C. There are some parts of the apparatus belonging to the boiler which you have not yet explained. What is the reason that the pipe *q*, which conveys the water from the cistern v to the boiler, is turned up at the lower end?

F. If it were not bent in that manner, the steam that is generated at the bottom of the boiler would rise into the pipe, and in a great measure prevent the descent of the water through it.

E. In this position I see clearly no steam can enter the pipe, because steam, being much lighter than water, must rise to the surface, and cannot possibly sink through the bended part of the tube. What does *m* represent?

F. It represents a stone suspended on a wire, which is shown by the dotted line: this stone is nicely balanced by means of a lever, to the other end of which is another wire connected with a valve at the top of the pipe *q*, that goes down from the cistern.

C. Is the stone so balanced as to keep the valve sufficiently open to admit a proper quantity of water?

F. It is represented by the figure in that situation. By a principle in hydrostatics *, with which you are acquainted, the stone is partly supported by the water: if then by increasing the fire, too great an evaporation take place, and the water in the boiler sink below its proper level, the stone also must sink, which will cause the valve to open wider, and let that from the cistern come in faster. If, on the other hand, the evaporation be less than it ought to be, the water will have a tendency to rise in the boiler; and with that the stone must rise, and the valve will, consequently, let the water in with less velocity: by this neat contrivance, the water in the boiler is always kept at one level.

E. What are the pipes *t* and *u* for?

F. They are seldom used, but are intended to show the exact height of the water in the boiler. The one at *t* reaches very nearly to the surface of the water when it is at the proper height: that at *u* enters a little below the surface. If then the water be at its proper height, and the cocks *t* and *u* be opened, *steam* will issue from the *former*, and *water* from the *latter*. But if the water be too *high*, it will rush out at *t* instead of steam; if too *low*, the steam will issue out at *u* instead of water.

C. Suppose things to be represented as in the plate, why will the water rush out of the cock *u* if it be opened? it will not rise above its level.

F. True: but you forget that there is a constant pressure of the steam on the surface of the water in the boiler which tends to raise the water in the pipe *u*. This pressure would force the water through the pipe, as in an artificial fountain. See Conversation VIII.

E. You said Captain Savery was the inventor of the steam-engine.

F. His invention went merely to raising water from pits and mines. But in its present improved state, the steam-engine is applied to a thousand useful and important purposes; and the improvements and modifications of late years have been very great. But it would occupy us too long, and take us very much from our purpose, were I to attempt more than this general description. I must refer you to treatises on the steam-engine for further information. The engine I have described acts by steam at low pressure: locomotives require high-pressure steam.

E. Explain to us the meaning of *high-pressure* steam.

F. When water is boiled in an open vessel, it begins to be

* See Hydrostatics, Conversation XI.

converted into steam as soon as its temperature reaches 212° Fahrenheit; and the bubbles, which you observe rising from the part of the vessel which is nearest to the fire, and ascending to the surface, are steam; and, under such circumstances, one pint of water will produce 1700 pints of steam; and the water, so long as the steam is free to escape, retains the temperature of 212° and no more, however great the fire may be; and also keeps the vessel, in which it is boiling, down to the same temperature, so long as any water remains.

C. Then I suppose that 212° is always the boiling point?

F. Not at all: it is the boiling point of *water*; and that only under the conditions in question.

E. Why do you lay so much stress on the word *water?* I thought that boiling hot was the same for all things boiling.

F. No. The temperatures at which liquids boil are very various; and each has its own boiling-point. You may remember the practice of besieged citizens in the feudal times, who poured boiling oil from the walls of the town on their assailants, which penetrated within their armour, and scalded them most fearfully, notwithstanding the heat lost in the operation. And no wonder; for whale oil boils at the high temperature of 630°. On the other hand, ether boils at the low temperature of 96°, and spirits of wine at the temperature of 173°.

E. Ah! now I see: 212° is the boiling point of *water*, but not necessarily of other liquids.

F. Not so fast, my dear. The water that is boiling in the kitchen is hotter than the water boiling in the garret. Water on a high mountain boils at a lower temperature than water boiled in a valley. At the top of Mont Blanc, for instance, Saussure found the boiling point of water to be 187°; which is 25° lower than its boiling point at the level of the sea.

C. What is the cause of these great differences?

F. Atmospheric pressure. Water in a valley has the whole of the atmosphere above it, and is *pressed upon* by a column equal in weight to about 30 inches of mercury, or 14¾ lbs. on the square inch; whereas water on a mountain has part of the atmosphere beneath it, and therefore only a portion above it and *pressing* upon it; and it is these differences of pressure that cause differences in the boiling-point.

E. Then I suppose, papa, that water boils at a very low temperature in a vacuum when there is no pressure?

F. It does; and partly on this principle depends a method of producing ice by the use of the air-pump. I can illustrate it, however, in a more direct way.—Take a clean Florence flask, and prepare a cork to fit it well. Boil some water in the flask,

over a lamp, and when on the full boil cork it tight and remove the lamp; when the boiling will immediately cease. Dip it now in a basin of *cold* water, and it will begin to boil again.

C. I see how this is.—The cold water condenses the vapour, with which the upper portion of the flask was filled, and thus removes its pressure; and consequently, in accordance with the laws that you have just given us, the water boils although it is a little colder.

F. You are right; and in this account I said that the cork must be placed in while the boiling goes on, and while, consequently, the upper part of the flask is full of steam and not of air: for the steam is at once condensed by the application of cold, but atmospheric air is but little affected.

C. But how does all this bear upon the locomotive engine, and on high-pressure steam?

F. From the reply you just gave me, I see that you understand the effect of pressure,—that the less it is, the easier water boils; and so, on the other hand, the greater it is, the higher is the temperature of boiling water. The boiling point is higher in the depths of a coal-mine, than on the surface above. And if, instead of condensing the steam, as we did in the Florence flask, we confine it, and add steam to steam, the water gets much hotter, and the elastic force of the steam becomes very great. This plan is pursued in the boilers of locomotive engines, and the steam is accumulated and kept to a pressure of 70 or 80 lbs. on the square inch, or 4 or 5 atmospheres, and in this state is allowed to enter the cylinders, and act by its elastic force against the pistons: the temperature of the water under these circumstances is from 306° to 315°; being about 100° hotter than water boiled in an open vessel.

C. I am very anxious to understand the construction of a locomotive engine, and the uses of its several parts.

F. The whole machine consists essentially of two parts, the engine properly so called, and the tender, which carries the water and fuel. The drawing before you (fig. 28.) is the section of a locomotive engine. The fire is contained in a large space A, called the *fire-box;* and the communication between the fire and the chimney B, instead of being by means of a single flue, consists of a large number of brass tubes C C C C, about 2 inches in diameter, passing bodily through the boiler D: the number and arrangement of these tubes depends on the purposes for which the engine is required. Two or three hundred, and even more, are introduced in powerful engines.

C. What is the object of all these tubes?

F. It is to increase the *heating surface;* that is, to allow the

fire and the boiler to come into contact over a very large amount of space. For in order to keep up the high pressure required, it is necessary that the steam be generated very rapidly; which is accomplished by having an intensely hot fire, and by presenting a large surface of water to the fire. If you look more carefully to the figure, you will see that this is commenced by an extension of the boiler E E E, which surrounds the fire-box; in fact, with the exception of the space occupied by the fire-bars F, and the fire-door G, the fire is bounded on all sides by the water in the boiler. But, large though this surface is, the tubes present many times as much more. As, for instance, Crampton's express engine shown at the Great Exhibition had 154 ft. of heating surface in the fire-box; and 2136 ft. in the tubes; making a total of 2290 square feet, being nearly equal to a single surface 48 ft. square. The engine made and exhibited by the Great Western Railway Company had 150 ft. of fire-box surface, and 1759 ft. of tube surface, in all 1909 square feet. And this engine had 305 tubes.

C. I had no idea that so large a surface of the boiler was presented to the fire; but I see the necessity of some such arrangement, in order to keep up the large supply of steam that is used and then escapes from the funnel. Where is this steam collected, and how is it applied?

F. The lower or shaded part of the boiler represents the water; the upper and light part the steam space. An elevation H is seen on the boiler sometimes near the funnel, sometimes elsewhere. It is a strong cylinder of iron, and is concealed from the eye within a dome. Inside this cylinder is the steam-pipe I, being the channel through which the steam passes, in order to do its work; its mouth is funnel-shaped, and then raised up high, in order as much as possible to prevent particles of water passing with the steam into the cylinders, technically termed *priming*, which is both inconvenient and mischievous. In front of the steam-pipe is the *regulator* K, consisting of two discs face to face, each having corresponding openings. In one position, the openings of one disc are faced by the perfect parts of the other, and the regulator is closed; in another position, the openings correspond, and the regulator is open. A rod L extends from the regulator through the steam space, and terminates in a handle or lever M, by which the engine-driver regulates the supply of steam.

E. Why, that is just like the little brass ventilator on the oven-door in the kitchen range.

F. It is; and the valve on the top of a balloon, which is opened or closed by ropes passing through the body of the bal-

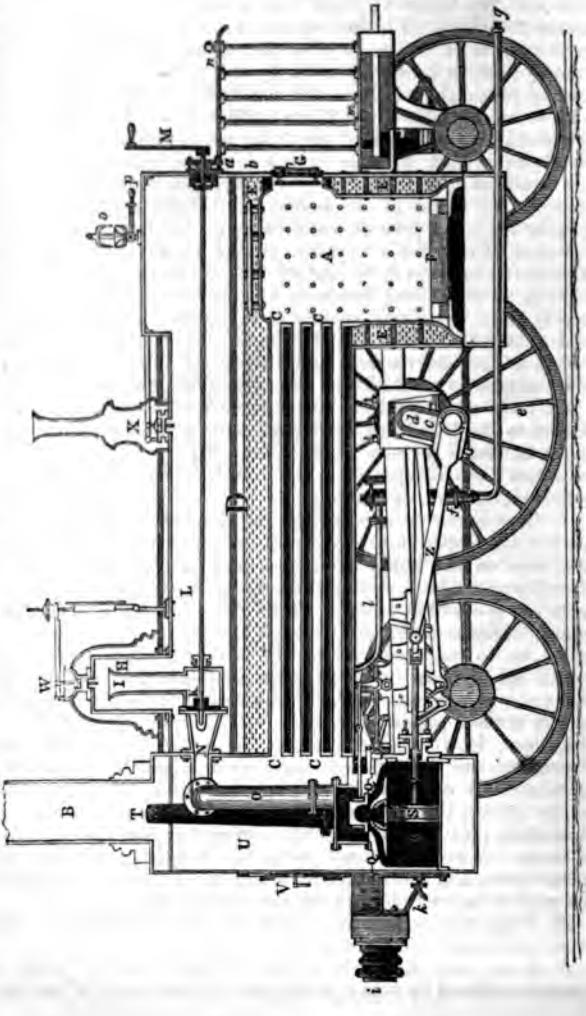


Fig. 25.

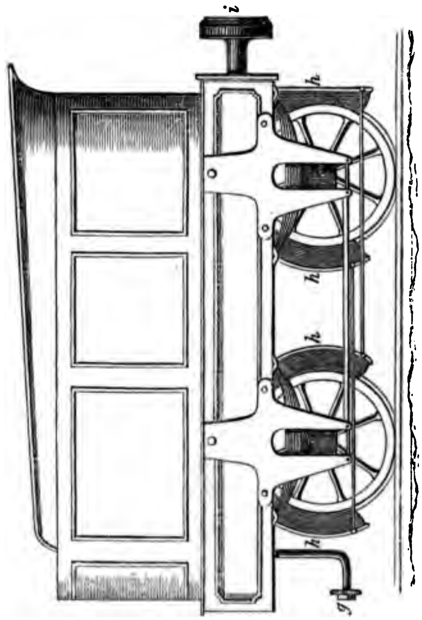


Fig. 28.

loon into the car, and by which gas is let out, is of a similar construction. On leaving the regulator, the steam passes onward by the pipe N, and diverges by two pipes, of which one O is seen. These lead respectively each to a valve-box, P; and from these boxes, the steam is admitted by the valves along the passages Q Q into the cylinder R, alternately on each side of the piston S. When the piston is at the end of the stroke, other valves open, and the steam, having done its work, is directed to the pipe T, called very justly the *blast-pipe;* for the exhausted steam is still in a high state of pressure, and rushes violently through the blast-pipe, and escapes in those well-known dense clouds, through the funnel B.

C. What a very strong draft this must cause in the chimney?

F. It does; and thus, after having done its proper duty in moving the piston, it here does the final duty analogous to that

of powerful bellows; for, rushing violently up the funnel, it greatly increases the current of heated air through the tubes, and hence promotes the intensity of the fire. The space U surrounding the blast-pipe is called the *smoke-box*, and is furnished with a door V, which, when open, exposes the ends of all the tubes, and is necessary that the engineer may pass a long rod through each tube, and clean it from dust and coke.

The boiler is protected by two safety-valves; one, W, over the dome M, which is adjusted to the regulated amount of pressure, 70 or 80 lbs.; or, in the engines I have quoted, 120 lbs. per square inch; and which lets off the steam, should it exceed the given pressure. The other, X, is within reach of the driver, and by which he regulates to a lower pressure, as he may require.

C. I see clearly how this prevents too much steam accumulating in the steam-space, and risking an explosion. But how does the driver discover that the steam-space itself does not vary in size? I mean, that the water continues to its proper level?

F. He has before him a strong glass tube, the lower end of which is fixed into a cock that enters the water, and the upper end into a cock that enters the steam-space. The water in this tube should show the same level as that in the boiler, and is a guide to the eye; as a still further security, there are two gauge cocks at *a* and *b*, one of which should blow off steam and the other water, if all is right.

E. But if the man finds too little water, how does he manage to put in more? it must boil away very fast to make so much steam.

F. He carries with him a supply of water in the *tender*; (the Great Western engine above mentioned carries 1600 gallons); and the engine is furnished with pumps, which are allowed to act, and pump water into the boiler as required, the motion of the engine working the pumps. The consumption of water depends upon the engine itself and on the amount of work done, and may vary from 20 gallons per mile and upwards; and 8 or 10 lbs. of coke will convert a cubic foot of water into steam.

C. And now tell us how the motion of the piston propels the engine.

F. The piston-rod Y is attached by the connecting-rod Z to the crank *c*, and thus turns the axle *d*, and with it the *driving-wheel e*. This wheel is sometimes coupled by a rod to another wheel, and sometimes not. It *grips* the rail as it revolves, and thus causes the engine to progress. The grip is caused by the

mere dead weight of the engine pressing upon the rails. Under certain unfavourable circumstances, the wheels slip round on the rails and do not move onward; this is when the rails are wet and greasy. In such cases, sand is thrown on the rail in front of the driving-wheel; for which purpose an iron box is fixed on the engine-frame, with a tube leading down in front of the driving-wheel and near to the rail.

The axle that carries the driving-wheel, carries also several eccentrics, to which are attached rods leading to the various steam valves; and these rods are so adjusted as to open and close their respective valves in the proper order. If to these I add that the tender (fig. 29.) consists of a large iron tank mounted on wheels; that the tank is connected with the pumps *f* by the pipes *g g*, that space is provided for the necessary quantity of coke, and that it is furnished with the *breaks x*, which by means of a lever and screw apply wooden blocks *h h h h* to the wheels when the engine is to be brought to a stand, I have explained the leading parts of a locomotive engine.

The engine has buffers or spring cushions *i*, and so has the tender; there are also buffers between the engine and tender to absorb the force of blows: *k* is a safety cock, for clearing the cylinder of water; *l* is the pipe through which the water passes from the pumps into the boiler; *m* is the foot-plate on which the driver stands, with the rail *n* for his protection; *o* is the steam whistle, which is really a brass bell, that is sounded by the rush of steam upon its edges from a circular opening around the lower hemisphere; *p* is the lever for opening a steam-way to the whistle.

C. Before we conclude, I should be glad to have some idea of the load that can be drawn by powerful engines and a few other data.

F. The Great Western engine can draw 120 tons, at the rate of 60 miles an hour; it is of 743 horse power. The weights are,

	Tons.	cwt.
Engine - - - -	31	0
Coke and Water - - -	4	0
Tender - - - -	9	0
Water - - - -	7	3
Coke - - - - -	1	10
	52	13

Cylinder 18 in. in diameter; length of stroke of piston 2 ft.; diameter of driving wheel 8 ft.; going 29 miles an hour with a load of 90 tons, it burns $20\frac{4}{5}$ lbs. of coke per mile.

CONVERSATION XVIII.

Of the Steam-Engine, and Pupin's Digester.

C. We have seen the structure of the steam-engine and its mode of operation; but you have not told us the uses to which it is applied.

F. The application of this power was at first devoted to the raising of water, either from the mines, which could not be worked without such aid, or to the throwing it into reservoirs, for the purpose of supplying places which are higher than the natural level of the stream.

E. I am sure, papa, steam is now applied to many more purposes than this. It would not be a very easy task to enumerate them all.

F. It would not indeed, my dear girl; it would be a far less difficult matter to tell you what it is not applied to. I can scarcely look round on anything about me which is not more or less indebted to this wondrous power of elasticity of vapour. Let us take the one example—railroad locomotion. A vessel of boiling water over a good fire flies away with a dozen or more carriages, each freighted with a score of human souls, and whisks them from east to west, from north to south, at the rates of 40, 50, 60, and more miles per hour. And the same power, in defiance of wind and wave, moves mighty ships even across the pathless and wide Atlantic.

E. The force of steam must be very great!

F. From a great variety of accidents that have happened through careless people, it appears that the expansive force of steam, suddenly raised, is much stronger than even that of gunpowder. At the cannon foundry in Moorfields, some years ago, hot metal was poured into a mould that accidentally contained a small quantity of water, which was instantly converted into steam, and caused an explosion that blew the foundry to pieces. A similar accident happened at a foundry in Newcastle, which occurred from a little water having insinuated itself into a hollow brass ball that was thrown into the melting pot.

C. These facts bring to my mind a circumstance that I have often heard you relate, as coming within your knowledge.

F. You do well to remind me of it. The fact is worth recording. A nobleman, who was carrying on a long series of experiments, wished to ascertain the strength of a copper vessel, and gave orders to his workmen for the purpose. The vessel, however, burst unexpectedly, and, in the explosion, it beat down the brick wall of the building in which it was placed, and was

by the force of the steam, carried 15 or 20 yards from it; several of the bricks were thrown 70 yards from the spot; a leaden pipe, suspended from an adjoining building, was bent into a right angle; and several of the men were so dreadfully bruised or scalded, that for many weeks they were unable to stir from their beds. A very intelligent person, one of the sufferers, who conducted the experiment, assured me that he had not the smallest recollection how the accident happened, or by what means he got to his bedroom after the explosion.

E. Is it by the force of steam that bones are dissolved in Papin's Digester, which you promised to describe?*

Fig. 30.

F. No; that operation is performed by the great heat produced in the digester. This is a representation of one of these machines. It is a strong metal pot, at least an inch thick in every part; the top is screwed down, so that no steam can escape but through the valve v.

C. What kind of a valve is it?

F. It is a conical piece of brass, made to fit very accurately, but easily movable by the steam of the water when it boils; consequently in its simple state, the heat of the water will never be much greater than that of boiling water in an open vessel. A steelyard is therefore fitted to it, and, by moving the weight w backwards or forwards, the steam will have a lesser or greater pressure to overcome. And, as it is the pressure of the atmosphere that causes the heat of boiling water to be greater in an open vessel than in one from which the air is exhausted, by confining the steam, the pressure may be increased to any given degree. If, for instance, a force equal to 14 or 15 pounds be put on the valve, the pressure upon the water will be double that produced by the atmosphere, and of course the heat of the water will be greatly increased.

C. Is there no danger to be apprehended from the bursting of the vessel?

F. If care be taken so as not to load this valve too much, the danger is not very great. But in experiments made to ascertain the strength of any particular vessel, the utmost precaution must be taken.

Under the direction of Mr. Papin, the original inventor, the bottom of a digester was torn off with a wonderful explosion; the blast of the expanded water blew all the coals out of the fire-

* See Mechanics, Conversation III.

place, the remainder of the vessel was hurled across the room, and striking the leaf of an oaken table an inch thick, broke it in pieces. Not the least sign of water could be discerned, and every coal was extinguished in a moment.

E. You have told us that water, and of course the steam with it, when under a high pressure, is hotter than ordinary boiling water; now, how can this be? for Mary scalded her arm dreadfully by carelessly allowing the steam of the kettle to touch it, and yet I saw the assistant at the Polytechnic put his hand into the jet issuing from the powerful steam boiler. He said, it was *cool* rather than *warm;* I must say, I hardly believed him.

F. He spoke the truth, nevertheless: for what think you is the first thing the steam does on getting out of the orifice; of course, it expands. Now you remember my having proved to you that bodies expanding take in heat; this is the case with high-pressure steam; it expands so greatly and so quickly, that it has not time, as it were, to acquire heat from the immense receptacle it has just left, and, therefore, abstracts it from anything it gets near; but when it has expanded to the full, as at a greater distance from the jet, the heat is distributed, and then it would scald.

CONVERSATION XIX.

Of the Barometer.

F. I shall proceed with an account of the barometer, which, with the thermometer, is to be found in almost every house. I will show you the principle of the barometer, without any regard to the frame to which it is attached.

A B is a glass tube, about 33 or 34 inches long, closed at top; D is a cup or small cistern, partly filled with quicksilver. I fill the tube with the quicksilver, and then put my finger upon the mouth, so as to prevent any of it from running out; I now invert the tube, and plunge it in the cup D. You see the mercury subsides three or four inches; this tube, if fixed to a graduated frame, will give you an idea of a barometer; and you know it is consulted by those who study and attend to the changes of the weather.

Fig. 31.

E. Why does not all the quicksilver run out of the tube?

F. Mercury, as you will find by referring back to the list of specific gravities, is 13·596 times heavier than water at the tem-

perature of 32°. You have also been told, when we talked of pumps, that the pressure of the atmosphere would balance a column of about 34 feet of water,—accurately speaking it is 33·464 feet. It ought, therefore, on the same principle, to balance 33·464 feet, or 401·568 inches, of mercury, divided by 13·596.

E. The quotient is,—let me see,—29·53 inches.

F. By this method Torricelli was led to construct the barometer.

He suspected that the pressure of the atmosphere was the cause of the ascent of water in the vacuum made in pumps, and that a column of water, between 33 and 34 feet high, was a counterpoise to a column of air which extended to the top of the atmosphere. And if so, that a column of mercury shorter than 34 feet, in proportion as mercury is heavier than water, would likewise sustain the pressure of the atmosphere; he obtained a glass tube for the purpose, and found his reasoning just.

C. Did he apply it to the purpose of a weather-glass?

F. No; it was not till some time after this that the pressure of the air was known to vary at different times in the same place. As soon as that was discovered, the application of the Torricellian tube to the examination of the changes of the weather immediately succeeded.

C. A barometer, then, is an instrument used for measuring the weight or pressure of the atmosphere.

F. That is the principal use of the barometer; if the air be *dense*, the mercury rises in the tube, and indicates fair weather; if it become *light*, the mercury falls, and presages rain, snow, &c.*

The height of the mercury in the tube, in this country, fluctuates between 28 and 31 inches.

E. Is the fluctuation of the mercury different in different parts of the world?

F. There are diurnal variations in the barometer, which depend on the geographical *position* of the place: the mercury falls at certain hours, and rises at other certain hours. Near the equator, the differences between the *maximum* and *minimum* are great, in high latitudes less.

		Great Ocean, Lat. 0° 0′.	Petersburg, Lat. 59° 66′.
Maximum (10 P.M.)	„	29·587 inches.	29·842.
Minimum (4 A.M.)	„	29·526.	29·841.
Difference		·061.	·001.

* See the rules at page 281.

There are two maxima and minima per day; and the times of these vary with the seasons; being nearer to noon in winter than in summer.

There are variations depending on the *seasons*; and they are less at the equator, and greater in high latitudes, as the following illustration will show:—

		Batavia, Lat. 6° 12′ S.	Petersburg, Lat. 59° 56′ N.
Winter (mean range)	„	0·110 inches.	1·451 inches.
Summer „ „	„	0·106.	0·784.
Difference		0·004.	0.667.

C. I see by these examples that, during a *day* in high latitudes, the variations in the height of the mercury are not great, but during a *year* they are great; and the reverse is the case in low latitudes.

F. It is so; but these periodic variations are often lost in the *accidental* variations, as they are termed, which arise from the weather, properly so called; and are due to rain, wind, storms, &c.; and which are very marked in high latitudes.

E. How high and how low has the barometer been noted in England?

F. The highest to which I can refer was 30·89 inches at Greenwich, in 1825, and the lowest in 1821, at the same place, 27·99 inches; the difference is 2·9 inches. The mean annual height at Greenwich is 29·87 inches, and the mean annual range 1·92 inches.

At Paris, the greatest height has been 30·7 inches, and the least 28·2 inches; the difference being 2·5 inches. The mean height then is 29·77 inches.

C. The scale of variation is the silvered plate, which is divided into inches and tenths of an inch: but what do you call the movable index?

F. It is called a *vernier*, from the inventor's name, and the use of it is to show the fluctuation of the mercury to the hundredth part of an inch. The scale of inches is placed on the right side of the barometer tube, the beginning of the scale being the surface of the mercury in the basin: the vernier plate and index are movable, so that the index may, at any time, be set to the upper surface of the column of mercury.

E. I have often seen you move the index, but I am still at a loss to conceive how you divide the inch into hundredth parts by it.

F. The barometer plate is divided into tenths; the length of the vernier is eleven tenths, but divided into ten equal parts.

C. Then each of the ten parts is equal to a tenth of an inch, and a tenth part of a tenth.

F. True: but the tenth part of a tenth is equal to a hundredth part, for you remember, that to divide a fraction by any number is to multiply the denominator of the fraction by the number, thus $\frac{1}{10}$ divided by $10 = \frac{1}{100}$.

Suppose the index of the vernier to coincide exactly with one of the divisions of the scale of variation, as 29·3.

E. Then there is no difficulty; the height of the barometer is said to be 29 inches and three tenths.

F. Perhaps, in the course of a few hours, you observe that the mercury has risen a very little; what will you do?

E. I will raise the vernier even with the mercury.

F. And you find the index so much higher than the division ·3 on the scale as to bring the figure 1 on the vernier even with the second tenth on the scale.

E. Then the whole height is 29 inches 3 tenths, and one of the divisions on the vernier; which is equal to a tenth and a hundredth; that is, the height of the mercury is 29 inches, 3 tenths, and 1 hundredth, or 29·31.

F. If figure 2 on the vernier stand even with a division on the scale, how should you call the height of the mercury?

E. Besides the number of tenths, I must add 2 hundredths, because each division of the vernier contains a tenth and a hundredth: therefore I say the barometer stands at 29·32: that is, 29 inches, 3 tenths, and 2 hundredths.

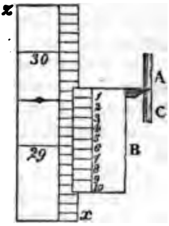


Fig. 32.

F. Here is a representation A C of the upper part of a barometer tube; the upper surface of the quicksilver stands between A and C: from *z* to *x* is part of the scale of variation: 1 to 10 is the vernier, equal to $\frac{11}{10}$ths of an inch, but divided into 10 equal parts. In the present position of the mercury, the figure 4 on the vernier coincides exactly with a line on the scale: and finding the index stand between the 6th and 7th divisions on the scale, I therefore read the height 29·64: that is, 29 inches, 6 tenths, and 4 hundredths.

C. If the mercury falls in the barometer, it must alter the level of the mercury in the reservoir below, and confuse the measuring.

F. It does; and to obviate this, the cistern below has an adjusting screw, in good barometers, by which the true level can

be restored at each observation. In instruments of the best construction, such as are used under Mr. Glaisher's auspices for standard observations, the cistern is made of glass with a leathern bottom; in the cistern, and visible to the eye, is an ivory point, directed downward toward the mercury; this point is the zero or spot from which the scale, which is on a brass tube, extending from end to end, was measured in the construction of the barometer: and by a screw, the leathern bottom is raised or lowered until the point just touches the mercury; and this is easily seen, for its shadow in the mercury at once tells when it is accurately there. Barometers not thus provided must be corrected for capacity, which is never to be relied on.

C. I suppose that with such an instrument the readings are absolutely true.

F. Indeed they are not. For you are aware that mercury varies in bulk, according to the temperature; and that therefore, what would be 30 inches on a cold day would be a little more than 30 inches on a hot day: for instance, a variation in temperature from 40° to 60° produces an expansion in the mercury at 30 inches, equal to a rise of ·054 of an inch. On this account it has been determined to reduce all observations to the temperature of 32°, or the freezing point of water.

C. And how is this done?

F. Extensive tables have been calculated, which are applicable to barometers, with *brass scales* extending from the cistern to the top of the mercurial column, which is the construction of the proper one I have just described. You will find them in "The Report of the Committee of Physics, including Meteorology," approved by the President and Council of the Royal Society, and published in 1840.

You will find these corrections for all temperatures from 0° to 100°; and for all heights from 20 inches to 31 inches.

C. Why did you mention brass scales?

F. Because the expansion of the brass can be as accurately calculated as that of mercury. So that the measuring rod, so to speak, being of one metal, and the thing to be measured being another metal, the tables can be made most accurate.

C. I have opened the "Report" at p. 84.; will you tell me how to use the table?

F. Suppose the barometer shows 30° while the temperature is 60°; facing these figures you find ·085, and on the top of the column is the sign (—) or minus, which shows that, in order to correct the barometer for temperature, or reduce it to what would have been its height, had the temperature been 32°, you subtract those figures from the observed height:

Observed height - - -	30°
Correction for temperature -	·085
Corrected height - - - - -	29·915

The following is a list of corrections to be made for observations of 30° at various temperatures:—

Temp. 51°	·060	Temp. 61°	·087
52	·063	62	·090
53	·066	63	·093
54	·068	64	·095
55	·071	65	·098
56	·074	66	·101
57	·076	67	·103
58	·079	68	·106
59	·082	69	·109
60	·085	70	·111

And, of course, they are all to be subtracted, as the mercury would be more contracted at 32° than at any of those higher temperatures.

C. Then it is necessary to have a thermometer near the barometer, to read both before you can arrive at the truth?

F. You will not reach the truth then; for there is another correction to make for the capillary action between the glass and the mercury; the effect of which is, to depress the mercury in the tube below its true level, by a certain quantity inversely proportional to the diameter of the tube. Tables, therefore, have been constructed to correspond with the various sizes of barometer tubes. These tubes should never be less than one-fifth or ·20 of an inch in diameter. The following is a table of corrections for tubes from one-fifth to three-fifths of an inch; and which are in all cases to be *added*.

Diameter of Tube.	Correction for	
	Boiled Mercury.	Unboiled.
·20 inches	·029	·060
·25 "	·020	·040
·30 "	·014	·028
.35 "	·010	·020
·40 "	·007	·014
·45 "	·005	·010
·50 "	·003	·007
·60 "	·002	·004

C. Then, supposing the tube of the barometer were ·40 or two-fifths of an inch, the observation that we have just now corrected for temperature, requires ·007 to be deducted; thus:—

Height corrected for temperature - -	29°·915
Correction for capillarity - - -	·007
True height - - - - -	29·908

F. Mr. Glaisher prefers, very justly, tables that give in one correction the total correction for both temperature and capillarity, and these, of course, are easily prepared from the above tables. I have given you the corrections for unboiled mercury, in order to show you the great effect produced by the omission of boiling; but no scientific instrument should be thus made. In addition to all these precautions, the tube must be accurately vertical; and the readings are to be made with the eye, and the back and fore part of the index, and the top of the mercury column all on the same level.

C. How much I thank you for these instructions; I had not the least idea that an observation of the barometer was so important an affair.

CONVERSATION XX.

Of the Barometer, and its application to the measuring of Altitudes.

C. Is the height of the atmosphere known?

F. If the fluid air were similar to water, that is, everywhere of the same density, nothing would be easier than to calculate its height. When the barometer stands at 30 inches, and the thermometer at 32°, the specific gravity of air is 773·28 times less than that of water*; but mercury is about 13·6 times heavier than water, consequently the specific gravity of mercury is to that of air as 773·28 multiplied by 13·6 is to 1; or mercury is 11,200 times heavier than air. In the case before us, a column of mercury, 30 inches long, balances the whole weight of the atmosphere; therefore, if the air were equally dense at all heights to the top, its height must be 10516·6 times 30 inches; that is, the column of air must be as many times longer than that of the mercury, as the former is lighter than the latter. Do you understand me?

C. I think I do; 10516·6 multiplied by 30 gives 315,498 inches, which are equal to 5 miles nearly.

* See Conversation VI.

F. That would be the height of the atmosphere if it were equally dense in all parts; but it is found that the air, by its elastic quality, expands and contracts, and that at 3½ miles above the surface of the earth, it is twice as rare as it is at its surface; that at 7 miles it is 4 times rarer; at 10½ miles it is 8 times rarer; at 14 miles it is 16 times rarer; and so on, according to the following

TABLE.

At the altitude of	3½	miles above the surface of the earth, the air is	2	times lighter than at the earth's surface.
	7		4	
	10½		8	
	14		16	
	17½		32	
	21		64	
	24½		128	
	28		256	

Now, if you were disposed to carry on the addition on one side, and the multiplication on the other, you would find that, at 500 miles above the surface of the earth, a single cubical inch of such air as we breathe would be so much rarefied as to fill a hollow sphere equal in diameter to the vast orbit of the planet Saturn.

E. Is it inferred from this that the atmosphere does not reach to any very great height?

F. Certainly; for you have seen that a quart of air at the earth's surface weighs but about 14 or 15 grains; and by carrying on the above table a few steps, you would perceive that the same quantity, only 49 miles high, would weigh less than the 16 thousandth part of 14 grains; consequently at that height its density must be next to nothing. From experiment and calculation it is generally admitted, that the atmosphere at the height of more than 45 or 50 miles above the earth's surface is not sufficiently dense to refract the rays of light; and that, in popular language, is usually denominated the height of the atmosphere.

C. By comparing the state of the atmosphere at the bottom and at the top of a mountain, should you perceive a sensible difference?

F. We must not trust to our feelings on such occasions. The barometer will be a sure guide. I will not trouble you with calculations, but mention two or three facts, with the conclusions to be drawn from them. In ascending the Puy-de-Dôme, a very high mountain in France, the quicksilver fell 3¼ inches; and the height of the mountain was found, by measure-

ment, to be 3204 feet. By a similar experiment upon Snowdon, in Wales, the quicksilver was found to have fallen $3\frac{8}{10}$ inches at the height of 3720 feet above the surface of the earth.

From these and many other observations, we may say roughly that in ascending any lofty eminence, the mercury in the barometer will fall $\frac{1}{10}$ of an inch for every 100 feet of perpendicular ascent. This number is not rigidly exact; and it varies with the actual height of the barometer, and with that of the thermometer; but for common purposes it will serve as it can be easily remembered. The three following observations were taken by Dr. Nettleton near the town of Halifax:—

Perpendicular Altitude in Feet.	Lowest Station of the Barometer.	Highest Station of the Barometer.	Difference.
102	29·78	29·66	0·12
236	29·50	29·32	0·27
507	30·00	29·45	0·55

E. What is the accurate rule for measuring elevations by the barometer?

F. You require a set of tables showing the number of feet of atmosphere, that counterpoise an inch of mercury for various temperatures, and when the barometer is at 30 inches. For instance, at 32° temperature an *inch* of mercury counterpoises a column of atmosphere of 868½ ft. in length; at 46° a column of 898·1 ft.; at 60°, a column of 927·7 ft.

The rule is: as the mean of the two barometers is to their difference, so is 30 inches, multiplied by the figure in the table, opposite to the mean of the two thermometers to the height required.

C. If, at the foot of a mountain, the barometer is 30 inches and the thermometer 60°; and on the top, the barometer is 28½ inches and the thermometer 32°; how am I to find the height of the mountain?

F. The mean of the barometer is $\frac{30+28\cdot5}{2}=29\cdot75$ in.

The mean of the thermometer is $\frac{60+32}{2}=46°$.

The difference of the barometer is $30-28\cdot5=1\cdot5$ in.

Opposite to 46° in the table is 898·1 in. Now say,

$$\text{As } 29\cdot75 : 1\cdot5 :: 30\times898\cdot1 : 1358 \text{ ft.}$$

E. Then the height of such a mountain is 1358 ft. And my rough calculation of 100 ft. for each tenth of an inch of mercury would have thrown me much out from the truth; for I see that the temperature of the two places of observation must be taken into account.

F. And you must understand that the barometric observations used must be first corrected.

Let me now ask you, are you aware how great a pressure you are continually sustaining?

E. No; it never occurred to me to speculate upon that. I feel no burden from it, therefore it cannot be very great.

F. You sustain every moment a weight equal to many tons, which, if it were not balanced by the elastic force of the air within the body, would crush you to pieces.

C. We might indeed have inferred that it was considerable, from the sensations that we felt when the air was taken from under our hands. But how, sir, do you make out the assertion?

F. When the barometer stands at 29·5 the pressure of the air upon every square inch is more than equal to 14 pounds — call it 14 pounds for the sake of even numbers — and the surface of a middle-sized man is 14½ feet; tell me now the weight he sustains.

C. I must multiply 14 by the number of square inches in 14½ feet. Now there are 144 inches in a square foot; consequently in 14½ feet there are 2088 square inches; therefore 14 pounds multiplied by 2088 will give 29,232, the number of pounds weight pressing upon such a person.

F. That is equal to about 13 tons; now, if Emma reckons herself half only the size of a grown person, the pressure upon her will be equal to 6½ tons.

E. What must the pressure upon the whole earth be?

F. This you may calculate at your leisure; I will furnish you with the rule;

"Find the diameter of the earth*, from which you will easily get the superficial measure in square inches, and this you must multiply by 14, and you may get the answer in pounds avoirdupois."

The earth's surface contains about 200,000,000 square miles, and as every square mile contains 27,876,400 square feet, there must be 5,575,280,000,000,000 square feet in the earth's surface, which number multiplied by the pressure on each square foot gives the whole weight of the atmosphere.

C. This is truly enormous!

F. But the pressure being equal in all possible directions, it has no effect in disturbing either the annual or diurnal motion of the earth.

C. What is the cause of the constant change in the height of the barometer?

* See Astronomy, Conversation VII. note, p. 84.

F. The fundamental cause is *heat;* indeed so much so, that Professor Kaemtz compared the barometer to a differential thermometer.

C. I remember this is a glass tube bent somewhat like the letter U standing erect, and with a bulb at each end; and according as one or other bulb is made warmer the air in it expands, and the liquid drop moves: but I cannot conceive the analogy between it and the barometer.

F. You have seen that, when heat expands air, it rises, and the denser air rushes into its place; now suppose the barometer in London were at 30 inches, and London suddenly became very cold, what would happen?

C. The air would condense and occupy less space, and the warmer air from the neighbourhood would flow in to fill up the blank.

F. Well; and so the column of air over London would increase in quantity, and therefore in weight, and the barometer would rise. But when you say warmer air would flow in, this implies that it is warmer at that moment elsewhere than at London. So that when the barometer rises, it proves a difference of temperature between two places; although the second place be at a great distance.

E. Why, papa, the barometer differs from every other instrument; for, as far as I know, they tell you only what goes on where they are.

C. And I can see too that our barometer would soon tell us if any neighbouring country became colder; for some of our air would flow away, we should have less over us, and our barometer would fall.

F. Yes; and, as a general rule, when the thermometer goes up, the barometer goes down.

E. But how are we to reconcile this, papa, with the fact that a fall in the barometer is a general sign of rain? I can imagine it to be a sign of wind.

F. We cannot, dear girl, enter into this complex subject now, but I can tell you enough to give you a tolerably clear idea of the subject. You remember my explanation of the fact of your seeing your breath in cold weather; now, if a cold mass of air is just full of, or, as it is termed, saturated with, moisture, it will not quite cause rain; so also if a hot mass is similarly circumstanced, it will hold a greater quantity in proportion of moisture but not cause rain; if, however, the two are mixed, the resultant temperature will not hold in solution the resultant moisture, and rain falls.

E. Then this is why it almost always rains when a cold wind follows warm fine weather?

F. Yes; and when the wind has prevailed for a time all the rain falls, and the weather becomes fine. Did you ever notice in fine summer weather that the morning may be clear; during the day floating clouds appear, and toward sunset they depart?

E. Oh, yes, papa; and are not blown away, they dissolve away.

F. Yes, this is actually the case: for the heat of the sun causes the moisture of the earth to rise; but when it reaches the cold upper regions, it is condensed into clouds; as the heat decreases these clouds become more condensed and heavy, and they descend. But on reaching the warmer lower regions, which are not nearly full of moisture, they dissolve and disappear.

C. What is the principle of the *aneroid* barometer? I have seen you read it, and have noticed that the hand points almost as correctly as the mercury does; and yet there is no visible agency.

F. It acts however by the weight or pressure of the air, as does the other; and could it be made in practice as perfect as it is in principle, it would be equally truthful for every case. It consists of an air-tight box 4 or 5 inches in diameter: it is partially exhausted of air, so as to be an imperfect vacuum, and is then hermetically sealed. Its front cover is a thin sheet of corrugated or grooved metal, which gives way under the pressure of the air; and is more or less acted on according as the pressure varies. These changes are too minute to be visible to the eye; but, by a system of levers, this minute motion acts on a short arm of a lever, producing more motion of the longer arm, which is multiplied by connection with another lever, and is finally transferred to a hand, which traverses a dial graduated to correspond to the barometer-scale.

CONVERSATION XXI.

Of the Thermometer.

F. As the barometer is intended to measure the different degrees of density of the atmosphere, so the thermometer is designed to mark the changes in its temperature, with regard to heat and cold.

E. Is there any difference between the thermometer that is attached to the barometer and that which hangs out of doors?

F. No; but, for the purposes of accurate observation, it is usual to have two instruments, one attached to, or near the

barometer, and the other out of doors to which neither the direct nor reflected rays of the sun should ever come.

C. Does not this thermometer consist of mercury inclosed in a glass tube which is fixed to a graduated frame?

F. That is the construction of Fahrenheit's thermometer: but when these instruments were first invented, about 200 years ago, air, water, spirits of wine, and then oil, were made use of; but these have given way to quicksilver, which is considered as the best of all the fluids, being highly susceptible of expansion and contraction, and capable of exhibiting a more extensive scale of heat. Fahrenheit's thermometer is chiefly used in Great Britain, and Reaumur's and the Centigrade thermometer on the Continent.

E. Is not this the principle of the thermometer, that the quicksilver expands by heat and contracts by cold?

F. It is: place your thumb on the bulb of the thermometer.

E. The quicksilver gradually rises.

F. And it will continue to rise till the mercury and your thumb are of equal heat. Now you have taken away your hand, you perceive the mercury is falling nearly as fast as it rose.

C. Will it come down to the point at which it stood before Emma touched it?

F. It will, unless, in this short space of time, there has been any change in the surrounding air. Thus the thermometer indicates the temperature of the air, or, in fact, of any body with which it is in contact. Just now it was in contact with your thumb, and it rose in the space of a minute or two from 56° to 62°; had you held it longer on it the mercury would have risen still higher. It is now falling. Plunge it into boiling water*, and you will find that the mercury rises to 212°. Afterwards you may, when it is cool, place it in ice, in its melting state, and it will fall to 32°.

E. Why are these particular numbers pitched on?

F. You will not perhaps be satisfied if I tell you, that the only reason why 212 was fixed on to mark the heat of boiling water, and 32 that to show the freezing point, was, because it so pleased M. Fahrenheit: this, however, was the case.

C. Will you explain the construction of the thermometer?

F. A B represents a glass tube, the end A is blown into a bulb, and this, with a part of the tube, is filled with mercury. In good thermometers the upper part of the tube approaches to a perfect vacuum, and of course the end B is hermetically sealed. If the tube be now placed in pounded ice, the mercury will sink

* This should be done very gradually, by holding it some time in the steam, to prevent its breaking by the sudden heat.

to a certain point, x, which must be marked on the tube, and on the scale opposite to this point 32 must be placed, which is called the freezing point. Then let it be immersed in boiling water, the mercury will rise, and after a few minutes become stationary. Against that point make another mark, and write on the scale 212 for the heat of boiling water. Between these points the scale is divided into 180 parts.

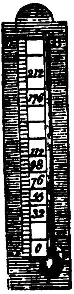


Fig. 33.

E. Why 180 parts?

F. Because you begin from 32, and if you subtract that number from 212, the remainder will be 180. Also, below 32, and above 212, are set off more divisions on the scale, equal to the others. The words *temperate heat*, *summer heat*, *blood heat*, *fever heat*, *spirits boil*, are often placed on the scale, opposite certain degrees. In common thermometers, these parts are equal; but in good thermometers, it does not follow that they are equal: for such thermometers are graduated by exposing them with the utmost nicety to other temperatures between 32° and 212°; and placing the graduation opposite the place to which the mercury rises. No reliance is to be placed on thermometers not thus graduated. The best thermometers are of small bore, and are graduated on the glass itself, those whose scales are on ivory are not trustworthy; and those on box-wood are continually varying, and are most difficult of correction.

E. This explains to me why the two 50's do not fall opposite to each other on your pair of thermometers; and the two 60's are nearer on a level, but still not quite so.

F. These differences arise from the irregularity in the tube, which cannot be obviated; and is thus neutralised in all standard instruments.

E. You said the scale was to be divided higher than boiling water, but without mentioning the extent.

F. The utmost extent of the *mercurial* thermometer, both ways, are the points at which quicksilver boils and freezes; beyond these it can be no guide: now the degree of heat at which mercury boils is 600, and it freezes when it is brought down as low as 39° or 40° below 0; consequently the whole extent of the mercurial thermometer is about 640 degrees, agreeably to this division.*

C. Is the cold ever so intense as to cause the mercury to sink 40° below the freezing point.

F. Not in this country, but it is in some parts of Lapland and

* The French divide the space between the freezing and boiling points of mercury into 100 equal divisions; and call the instrument thus constructed the *centigrade* thermometer.

Siberia; and even here artificial cold may be produced equal to this; as, for instance, by solid carbonic acid. It is usual to have thermometers for their particular uses; as for instance, an instrument for meteorological observations need not be graduated beyond or indeed so high as boiling water; nor need it, for temperate latitudes go below 0°.

The *minimum* thermometer is supplied with spirit instead of mercury, and shows the lowest temperature to which it may have been exposed since the last observation. A small glass thread is within the spirit, and, by inverting the instrument, its end is made to coincide with the level of the spirit; as the spirit falls, it falls with it; but when it begins to rise, the glass index remains behind, and shows the lowest temperature.

The *maximum* thermometer is supplied with mercury, and carries a steel index; as the mercury rises, it carries the index with it; but when it falls, it leaves the index behind, which shows the greatest height the mercury has attained. The steel index is brought back by means of a little magnet.

The index of this maximum thermometer is apt to get entangled in the mercury, and the column will break and cause inconvenience; on which account the jurors of the Great Exhibition, especially Mr. Glaisher, suggested an improvement, which has been successfully effected by Messrs. Negretti and Zambra. They have inserted a small piece of glass near the bulb and within the tube, which it nearly fills. As the temperature increases, the mercury passes this piece of glass; but, when the temperature falls, the glass acts as a valve or plug, and fills the bend, and so prevents the return of the mercury.

The *differential* thermometer consists of a horizontal tube, bent upwards at each end, and terminating in glass bulbs. With the exception of a small drop of liquid, the apparatus is filled with air; and is so constructed, that when the drop of the liquid is at the centre or zero point of the horizontal tube, the air in the bulbs has the same pressure; but according as one or other bulb is exposed to a higher or lower temperature, the drop of liquid moves this way or that, and so indicates the difference of temperature. This instrument is, as you see, an *air* thermometer.

CONVERSATION XXII.

Of the Thermometer.

C. Is quicksilver, when frozen, a solid metal, like iron and other metals?

F. It is thus far similar to them, that it is malleable, or will bear hammering. And when quicksilver boils, it goes off in vapour like boiling water, only much slower. Hence it has been inferred, that all bodies in nature are capable of existing either in a *solid*, *fluid*, or *aëriform* state, according to the degree of heat to which they are exposed.

E. I understand that water may be either solid, as ice, or in its fluid *natural* state, or in a state of vapour or steam.

F. I do not wonder that you call the fluid state of water its natural state, because we are accustomed, in general, to see it so; and when it is frozen to ice, there appears to us, in this country, a violence committed upon nature. But if a person from the West or East Indies, who had never seen the effects of frost, were to arrive in Great Britain during a severe and long-continued one, such as formerly congealed the surface of the Thames, unless he were told to the contrary, he would conclude that ice was some mineral, and naturally solid.

E. Does it never freeze in the East or West Indies?

F. It seldom freezes, unless in very elevated situations, within 35 degrees of the equator north and south; it scarcely ever hails in latitudes higher than 60°. In our own climate, and indeed in all others between 35° and 60°, it rarely freezes till the sun's meridian altitude is less than 40 degrees. The coldest part of the 24 hours is generally about an hour before sunrise, and the warmest part of the day is usually between two and four o'clock in the afternoon.

C. Are there no degrees of heat higher than that of boiling mercury?

F. Yes, a great many: brass will not melt till it is heated more than six times hotter than boiling mercury; and to melt cast-iron requires a heat more than six times greater than this.

E. By what kind of thermometer are these degrees of heat measured?

F. The ingenious Mr. Wedgewood invented a thermometer for measuring the degrees of heat up to 32,277° of Fahrenheit's scale.

C. Can you explain the structure of this thermometer?

F. All argillaceous bodies, or bodies made of clay, are diminished in bulk by the application of great heat. The diminution commences in a dull red heat, and proceeds regularly as the heat increases, till the clay is vitrified, or transformed into a glassy substance. This is the principle of Mr. Wedgewood's thermometer.

E. Is vitrification the limit of this thermometer?

F. Certainly. The construction and application of this in-

strument are extremely simple, and it marks all the different degrees of ignition, from the red heat, visible only in the dark, to the heat of an air-furnace. It consists of two rulers fixed on a plane, a little farther asunder at one end than at the other, leaving a space between them. Small pieces of alum and clay, mixed together, are made just large enough to enter at the wide end; they are then heated in the fire with the body whose heat is to be ascertained. The fire, according to its heat, contracts the earthy body, so that, being applied to the wide end of the gauge, it will slide on towards the narrow end, less or more, according to the degree of heat to which it has been exposed.*

Each degree of Mr. Wedgewood's thermometer answers to 130 degrees of Fahrenheit, and he begins his scale from red heat fully visible in daylight, which he finds to be equal to 1077° of Fahrenheit's scale, if it could be carried so high.

Here is a small scale of heat, as it is applicable to a few bodies:

SCALE OF HEAT.

Extremity of Wedgewood's scale - -		- 32277°
Cast-iron melts - - - -	at	- 2786
Fine gold melts - - - -		- 2016
Fine silver melts - - - -		- 1873
Brass melts - - - -		- 1869
Red heat visible by day - - -		- 980
Mercury boils - - - -	at	- 671
Lead melts † - - - -		- 612
Bismuth melts † - - - -		- 476
Tin melts † - - - -		- 442
Milk boils - - - -		- 213
Water boils - - - -		- 212
Heat of the human body - - - -		- 92 to 97
Water freezes - - - -		- 32
Milk freezes - - - -		- 30
A mixture of snow and salt sinks the thermometer to - - - -		- 0
Mercury freezes - - - -		- —40

C. You said that Reaumur's thermometer was chiefly used abroad; what is the difference between that and Fahrenheit's?

* We have in the former parts of this work observed that all bodies are expanded by heat. The diminution of the argillaceous substances made use of by Mr. Wedgewood *appears* to be an exception: but as the contraction of these does not commence till they are exposed to a red heat, it may probably be accounted for from the expulsion of the fluid particles, rather than from any real contraction of the solids.

† If these three metals be mixed together by fusion in the proportion of 5, 8, and 3, the mixture will melt in a heat below that of boiling water.

F. Reaumur places the freezing point at 0, or zero, and each degree of his thermometer is equal to $2\frac{1}{4}$, or $\frac{9}{4}$ degrees of Fahrenheit's.

E. What does he make the heat of boiling water?

F. Having fixed his freezing point at 0, and made one of his degrees equal to $2\frac{1}{4}$ of Fahrenheit's, the heat of boiling water must be 80°.

C. Let me see. The number of degrees between the freezing and boiling points on Fahrenheit's thermometer is 180, which, divided by $2\frac{1}{4}$, or 2·25, gives 80 exactly.

F. You have then a rule by which you may always convert the degrees of Fahrenheit into those of Reaumur:—"Subtract 32 from the given number, and multiply by the fraction $\frac{4}{9}$." Tell me, Emma, what degree on Reaumur's scale answers to 167° of Fahrenheit.

E. Taking 32 from 167 there remains 135, which, multiplied by 4, gives 540, and this, divided by 9, gives 60. So that 60° of Reaumur answers to 167° of Fahrenheit.

C. How shall I reverse the operation, and find a number on Fahrenheit's scale that answers to a given one on Reaumur's?

F. "Multiply the given number by the improper fraction $\frac{9}{4}$, and add 32 to the product." Tell me what number on Fahrenheit's scale answers to 40 on Reaumur's.

C. If I multiply 40 by 9, and divide the product by 4, I get 90; to which, if 32 be added, the result is 122. This answers to 40 on Reaumur's scale.

F. What numbers on Reaumur's scale will answer to 76°, 98°, and 112° of Fahrenheit; that is, to summer heat, blood heat, and fever heat?

E. The numbers are $19\frac{1}{2}$, $29\frac{1}{3}$, and $35\frac{1}{2}$ nearly; for

$$(76-32) \times \tfrac{4}{9} = \frac{176}{9} = 19{\cdot}5.$$

$$(98-32) \times \tfrac{4}{9} = \frac{264}{9} = 29{\cdot}33, \&c.$$

$$(112-32) \times \tfrac{4}{9} = \frac{320}{9} = 35{\cdot}55, \&c.$$

Similar rules may be employed with regard to the Centigrade thermometer; only that the multipliers must be $\frac{5}{9}$ and $\frac{9}{5}$ instead of $\frac{4}{9}$ and $\frac{9}{4}$.

C. Are there any other thermometers?

F. Yes; several. A very ingenious one invented by M. Breguet. A thin riband of platinum is soldered to one of gold, and the compound riband is made into a helix. Now, as these

two metals expand differently for the same increments of temperature, the helix either twists or untwists, and carries with it an index. The most delicate of all measures of heat is the thermo-electric pile; but as you cannot understand this until we have some conversation on electricity, I must be content with telling you, that directly you enter a room it will announce an increase of temperature, and it has been known to indicate the temperature of insects.

CONVERSATION XXIII.

Of the Pyrometer and Hygrometer.

F. To make our description of philosophical instruments more perfect, I shall to-day show you the construction and uses of the pyrometer and hygrometer, and conclude, to-morrow, with an account of the rain-gauge, and some directions for judging of the weather.

E. What do you mean by a pyrometer?

F. It is a Greek word, and signifies a fire-measurer. The pyrometer is a machine for measuring the expansion of solid substances, particularly metals, by heat. This instrument will render the smallest expansion sensible to the naked eye.

C. Is all this apparatus necessary for the purpose?

F. This, as far as I know, is one of the most simple pyrometers, and admitting of an easy explanation; I have chosen it in preference to a more complicated instrument, which might be susceptible of greater nicety.

To a flat piece of mahogany, A A, are fixed three studs, B C and D, and at B there is an adjusting screw P. H F is an index,

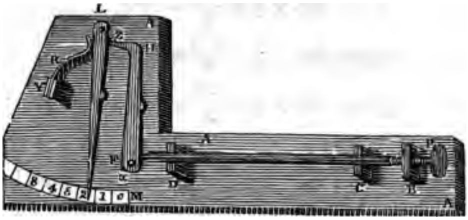


Fig. 34.

turning very easily on the pivot F, and L S is another, turning on L, and pointing to the scale M N. R is a part of a watch-

spring fixed at Y, and pressing gently upon the index L S. Here is a bar of iron, at the common temperature of the surrounding air: I lay it in the studs C and D, and adjust the screw P, so that the index L S may point to 0 on the scale.

C. The bar cannot expand without moving the index F H, the crooked part of which pressing upon L S, that also will be moved, if the bar lengthens.

F. Try the experiment; friction, you know, produces heat; take the bar out of the nuts, rub it briskly, and then replace it.

C. The index L S has moved to that part of the scale which is marked 2. It is now going back. How do you calculate the length of the expansion?

F. The bar presses against the index F H at F, and that again presses against L S at z, and hence they both act as levers.

C. And they are levers of the third kind; for in one case the fulcrum is at x, the power at F, and the point z to be moved may be considered as the weight; in the other, L is the fulcrum, the power is applied at z, and the point S is to be moved.*

F. The distance between the moving point F and H is 20 times greater than that between x and F; the same proportion holds between L S and L z; from this you will get the spaces passed through by the different points.

E. Then as much as the iron bar expands, so much will it move the point F, and of course the point z will move twenty times as much; so that if the bar lengthened $\frac{1}{10}$th of an inch, the point z would move $\frac{20}{10}$ths, or 2 inches. By the same rule, the point S will move through a space 20 times as great as the point z.

F. There are two levers, then, each of which gains power, or moves over space, in the proportion of 20 to 1; consequently, when united, as in the present case, into a compound lever, we multiply 20 into 20, which makes 400; and therefore if the bar lengthen $\frac{1}{10}$th of an inch, the point S must move over 400 times the space, or 40 inches. But suppose it only expands $\frac{1}{400}$th part of an inch, how much will S move?

C. One inch.

F. But every inch may be divided into tenths, and consequently, if the bar lengthen only the $\frac{1}{4000}$th part of an inch, the point S will move through the tenth part of an inch, which is very perceptible. In the present case the point S has moved two inches; therefore the expansion is equal to $\frac{2}{400}$ths, or $\frac{1}{200}$th part of an inch. An iron bar, three feet long, is about $\frac{1}{70}$th part of an inch longer in summer than in winter.

* For an account of the different levers, see Mechanics, Conversations XV. and XVI.

C. I see that, by increasing the number of levers, you might carry the experiment to a much greater degree of nicety.

F. There are other pyrometers besides this—Daniell's is the best. It consists of a bar of platinum, or of wrought iron, placed in a black-lead tube. When this is placed in a furnace the metal expands, and pushes forward a little piece of porcelain, which is so adjusted as to remain wherever it is pushed to; and, therefore, when the instrument is taken from the fire it may be examined, and the degree of expansion observed.

Well, let us now proceed to the hygrometer, which is an instrument contrived for measuring the different degrees of moisture in the atmosphere.

E. I have a weather-house that I bought at a fair, which tells me this; for if the air is very moist, and thereby denotes wet weather, the man comes out; and in fair weather, when the atmosphere is dry, the woman makes her appearance.

C. How is the weather-house constructed?

F. The two images are placed on a kind of lever, which is sustained by catgut; and catgut is very sensible to moisture, twisting and shortening by moisture, and untwisting and lengthening as it becomes dry. On the same principle is constructed another hygrometer. A B is a catgut string, suspended at A with a little weight B, that carries an index C round a circular scale D E on a horizontal board or table; for, as the catgut becomes moist, it twists itself, and untwists when it approaches to a drier state.

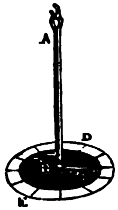


Fig. 35.

E. Then the degrees of moisture are shown by the index, which moves backwards and forwards by the twisting and untwisting of the catgut. Does all string twist with moisture?

F. Yes. Take a piece of common packthread, and on it suspend a pound weight in a vessel of water, and you will see how soon the two strings are twisted round one another.

C. I recollect that the last time the lines for drying the linen were hung out in the garden, they appeared to be much looser in the evening than they were next morning, so that I thought some person had been altering them. A sudden shower of rain has produced the same effect in a striking manner.

E. Sometimes, when sudden damp weather has set in, the string of the harp has snapped when no person has been near it.

F. These are the effects produced by the moisture of the air; the damp of night always shortens hair and hempen lines; and, owing to the changes to which the atmosphere in our

climate is liable, the harp, violin, &c., that are set to tune one day, will need some alteration before they can be used the next.

Here is a sensible and very simple hygrometer: it consists of a piece of whip-cord or catgut, fastened at A, and stretched over several pulleys, B, C, D, E, F: at the end is a little weight W, to which is an index pointing to a graduated scale.

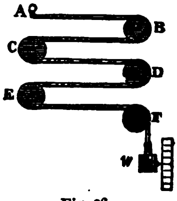


Fig. 36.

C. Then, according to the degree of moisture in the air, the string shortens or lengthens, and of course the index points higher or lower.

F. Another kind of hygrometer consists of a piece of sponge E, prepared and nicely balanced on the beam x y; and the fulcrum z lengthened out into an index pointing to a scale A B.

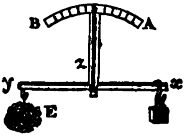


Fig. 37.

E. Does the sponge imbibe moisture sufficiently to become a good hygrometer?

F. Sponge of itself will answer the purpose; but it is made much more sensible in the following manner:

After the sponge is well washed from all impurities and dried again, it should be dipped into water or vinegar, in which sal ammoniac, salt of tartar, or almost any other saline substance, has been dissolved, and then suffered to dry, when it should be accurately balanced.

C. Do the saline particles, in damp weather, imbibe the moisture and cause the sponge to preponderate?

F. They do. Instead of sponge, a scale may be hung at E, in which must be put some kind of salt that has an attraction to the watery particles that float in the air. Sulphuric acid may be substituted in the place of salt; but this is not fit for your experiments, because a little spilt over will destroy your clothes; otherwise, it makes a very sensible hygrometer. Chloride of lime will do.

E. I have heard the cook complain of the damp weather when the salt becomes wet by it.

F. Right; the salt-box in the kitchen is not a bad hygrometer; and various others you may easily construct, as your knowledge of natural substances becomes extended.

E. But, papa, I have frequently seen you consult a kind of double thermometer, and heard you make remarks about the moisture of the day.

F. You are right; this is Mason's hygrometer; it is some-

times called a psychrometer, from a Greek word signifying *cold*. I will show it you. You observe it consists of two delicate thermometers; one of them is covered with book muslin, from which a few silk threads dip into a vessel of water, so that the muslin is always wet. The wet thermometer is lower than the dry: can you tell me why, Charles?

C. Because the moisture from the muslin evaporates into the air; and evaporation always produces cold.

F. You are right: and you can also see that the drier the weather, the greater will be the evaporation, and the colder will the bulb become. So that the greater the difference of temperature between the two bulbs, the drier is the air. Tables are constructed, so that on looking for the two temperatures we find set against them the percentage of moisture of the air.

C. I have heard you speak of Daniell's hygrometer.

F. It is a glass tube like an inverted ∩ with a bulb at each end: one bulb contains ether, and in it is a small and very delicate thermometer; the other bulb is covered with muslin. All the air is extracted from the tube, so that it only contains the vapour of ether. The muslin is to be wetted with ether; the drier the air is, the faster this evaporates: the cold produced condenses the vapour of ether within the tube, fresh vapour rises from the ether in the other bulb, and it becomes colder. Presently it becomes so cold that the moisture of the air is deposited on the bulb. The operation is now completed, and the temperature of the little thermometer is noted. This is called the *dew-point*.

E. I see that the dry thermometer is now standing at 60°, and the wet at 54°; what am I to understand by this?

F. I will open Mr. Glaisher's valuable Hygrometric Tables, and see the figures that stand facing these temperatures; and explain their meaning.

1. *Temperature of the dew point*, 49°·8; from which you are to understand, that if the temperature, as shown by the dry bulb, were reduced to 49°·8, the moisture in the air would be condensed, and it would rain. So as there are 10°·2 for the temperature to fall, and it is now getting warmer, we are tolerably sure it will not rain to-day. Daniell's hygrometer shows the dew-point at once; but it is not convenient at all times and in all places to have ether at hand; whereas rain-water for the wet-bulb thermometer is at hand in all parts of the world. When the two thermometers are together, no evaporation is occurring, the air being saturated with moisture, and it rains.

2. *Elastic force of vapour in inches of mercury*, 0·371 in.;

which means that the total pressure of the aqueous vapours, now diffused in the air, is equal to a column of mercury of the above height; so that whatever may be the height of the barometer, the above portion is due to aqueous vapour.

3. *Weight of vapour in a cubic foot of air*, 4·17 grains. A thousand cubic inches of dry air, when the thermometer is at 60°, and the barometer at 30 in., weigh 308 grains. A cubic foot of dry air at the standard temperature of 32°, and with the barometer at 30 in. weighs 563·2154 grains. The actual weight of the aqueous vapours diffused in a cubic-foot of air, is now 4·17 grains.

4. *Weight of vapour required for saturation of a cubic-foot of air*, 1·70 grains; which means that the air, under present circumstances, holding, as it does, 4·17 grains per cubic foot, is able to dissolve only 1·70 grains more; if therefore it is exposed to a greater degree of humidity, dew will be deposited or rain will fall.

C. Then there are two causes that may produce rain; if the air becomes sufficiently cold, the moisture will no longer be retained; or if more moisture be presented to the air than it can contain, it will be deposited in dew or rain; if both these changes occur simultaneously, the rain will be greater and more abundant.

5. *Degree of saturation* (complete saturation, 1·00), ·710; which means that if 1 represents the state of the air when quite saturated with moisture, ·71 represents its present state; which is therefore 71 per cent., about seven-tenths saturated, leaving therefore a capacity for three-tenths more.

6. *Weight, in grains, of a cubic foot of air.*

Barometer	28·0	inches,	494·4	grains.
„	28·5	„	503·2	„
„	29·0	„	512·0	„
„	29·5	„	520·8	„
„	30·0	„	529·6	„
„	30·5	„	538·4	„
„	31·0	„	547·2	„

This column expresses the actual weight of a cubic foot of air under the present circumstances of containing 71 per cent. of moisture. So that, if the barometer shall now be standing at 30 inches, the weight of a cubic foot of air would be 529·6 inches.

I must refer you to Kaemtz's or to Daniell's Meteorology, and to Mr. Glaisher's Tables, for further information of the

uses of this instrument; I shall here merely mention that it must be placed in the shade with a north aspect, not too near walls, and about four feet from the ground.

CONVERSATION XXIV.

Of the Rain-Gauge.

C. Does the rain-gauge measure the quantity of rain that falls?

F. It shows the height to which the rain would rise on the place where it is fixed, if there were no evaporation, and if none of it were imbibed by the earth. A funnel A communicates with a cylindric tube B. The diameter of the funnel is exactly 12 inches, and that of the tube is 4 inches. Tell me, Emma, what proportion the area of the former has to that of the latter.

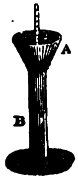


Fig. 38.

E. I remember that all similar plane surfaces bear the same proportion to one another that the squares of their like dimensions have. Now the square of 12 is 144, and the square of 4 is 16, therefore the proportion of the area of the funnel is to that of the tube as 144 to 16.

F. But 144 may be divided by 16, without leaving a remainder.

C. Yes; 9 times 16 is 144, consequently the proportion is as 9 to 1; that is, the area of the funnel, is 9 times greater than that of the tube.

F. If then the water in the tube be raised 9 inches, the depth of rain fallen will, in the area of the funnel, which is the true gauge, be only one inch.

C. Does the little graduated rule mark the elevation?

F. Yes, it does. It is a floating index divided into inches.

E. If then the float be raised 1 inch, is the depth of water reckoned only $\frac{1}{9}$ of an inch?

F. Just so: and each nine inches in length being divided into 100 equal parts, the fall of rain can be readily estimated to the $\frac{1}{100}$ part of an inch. Rain-gauges should be varnished or well painted; and as much water should be first poured in as will raise the float to such a height, that 0, or zero, on the ruler, may coincide with the edge of the funnel.

C. This is not like your rain-gauge.

F. Mine is a cubical zinc box, 10 inches square. It is open above; and presents a funnel mouth to the sky, having a small hole in the centre, through which the rain-water runs into the vessel. There is a pipe, through which I pour out what has

been collected, and measure it in a glass measure, graduated to cubic inches and fifths. Hence one inch of rain produces $10 \times 10 = 100$ cubic inches of water, of which I could measure easily the hundredth or even thousandth part, and this would represent the $\frac{1}{100}$th or $\frac{1}{1000}$th of the inch of rain.

You have now a pretty full account of all the instruments necessary for judging of the state of the weather, and for comparing, at different seasons, the various changes as they happen.

E. Yes; the *barometer* informs us how *dense* the atmosphere is; the *thermometer* enables us to ascertain its *heat;* the *hygrometer* what degree of *moisture* it contains; and by the *rain-gauge* we learn how much rain falls in a given time.

F. The rain-gauge must be fixed at some distance from all buildings which might in any way shelter it from particular driving winds; and the height at which the surface of the funnel is from the ground must be ascertained.

C. Does it make any difference in the quantity of rain collected, whether the gauge stands on the ground, or some feet above it?

F. Very considerable: as that which I have described is a cheap instrument, one may be placed on the top of the house, and the other on the garden wall, and you will find the difference much greater than you would imagine. — I will now give you some rules for judging of, and predicting, the state of the weather, which are taken from writers who have paid the most attention to these subjects, and which my own observations have verified.

1. The rising of the mercury presages, in general, fair weather, and its falling foul weather, as rain, snow, high winds, and storms. When the surface of the mercury is convex, or stands higher in the middle than at the sides, it is a sign the mercury is then in a rising state; but if the surface be concave or hollow in the middle, it is then sinking.

2. In very hot weather, the falling of the mercury indicates thunder.

3. In winter, the rising presages frost; and in frosty weather if the mercury falls three or four divisions, there will be a thaw. But in a continued frost, if the mercury rises it will certainly snow.

4. When wet weather happens soon after the depression of the mercury, expect but little of it; on the contrary, expect but little fair weather, when it proves fair shortly after the mercury has risen.

5. In wet weather, when the mercury rises much and high, and so continues for two or three days before the bad weather

is entirely over, then a continuance of fair weather may be expected.

6. In fair weather, when the mercury falls much and low, and thus continues for two or three days before the rain comes, then a great deal of wet may be expected, and probably high winds.

7. The unsettled motion of the mercury denotes unsettled weather.

8. The words engraved on the scale are not so much to be attended to as the rising and falling of the mercury; for if it stand at *much rain*, and then rises to changeable, it denotes fair weather, though not to continue so long as if the mercury had risen higher. If the mercury stands at fair, and falls to changeable, bad weather may be expected.

9. In winter, spring, and autumn, the sudden falling of the mercury, and that for a large space, denotes high winds and storms; but in summer it presages heavy showers, and often thunder. It always sinks lowest of all for great winds, though not accompanied with rain; but it falls more for wind and rain together than for either of them alone.

10. If, after rain, the wind change into any part of the north, with a clear and dry sky, and the mercury rises, it is a certain sign of fair weather.

11. After very great storms of wind, when the mercury has been low, it commonly rises again very fast. In settled fair weather, unless the barometer sink much, expect but little rain. In a wet season, the smallest depressions must be attended to; for when the air is much inclined to showers, a little sinking in the barometer denotes more rain. And in such a season, if it rise suddenly fast and high, fair weather cannot be expected to last more than a day or two.

12. The greatest heights of the mercury are found upon easterly and north-easterly winds; and it may often rain or snow, the wind being in these points, while the barometer is in a rising state, the effects of the wind counteracting. But the mercury sinks for wind as well as rain in all other points of the compass.

The observation of these and other rules which you will collect from experience will in a short time render you both as "*weatherwise*" as persons can in truth be, in so variable a climate as this.

If the wet and dry bulb thermometers are carefully observed as well as the barometer, a very accurate knowledge may be obtained of the probable changes that are about to take place.

APPENDIX TO PNEUMATICS.

Of Air, as a vehicle of heat and moisture —Of Rain, Dew, Meteoric Stones.

The causes which determine the distribution of heat over the earth's surface are, as has been shown in Conversation X. on Astronomy, either the direct influence of the solar rays, or the communication of heat by the air, from one part of the earth's surface to another. The first of these depends on the latitude of the place, by which the intensity of the heat and light from the sun, and also the length of the day, are determined. But the intensity of the sun's rays, when they strike upon any place, is as the quantity that falls on a given space; and, of course, the nearer the sun is to the zenith of any place at a given instant, the greater the intensity of heat produced by his rays.

Moreover, the heat of an entire day depends on the length of the day, as well as on the sun's elevation; and as the day is longer where the distance from the zenith is greater, the inequality in the distribution of heat, arising from one of these causes, compensates that which proceeds from the other, and brings their combined effects much nearer to an equality than could be imagined.

The effects of the direct influence of the sun are greatly modified by the transportation of the temperature of one region into another. Heat expands air, and it thus becomes specifically lighter; but the columns of air, which become lighter by the action of the sun's rays, are displaced by those that are heavier; and hence there is a general tendency in the air to move from the poles towards the equator, a circumstance which is admirably calculated to moderate the extrémes of temperature.

The sea, upon a similar principle, is preserved of a moderate temperature, for the heavier columns of a fluid displace those that are lighter. Hence the waters of the ocean are of a more uniform temperature, which temperature communicates itself to the surrounding air.

The effect of great continents is the reverse of this, and is favourable to the extremes of heat and cold. High mountains, especially if covered with snow, may increase the rigour of a cold climate, or temper the heat of a warm one.

Forests tend to increase the cold, by preventing the sun's rays

from striking on the ground. Evaporation, as we see by the wet bulb, produces cold; of course, countries that abound in marshes and lakes are subject to an increase of severe cold. And it is an admirable provision in nature, that in the act of the congelation of water into ice, a great deal of heat is given out, which in some degree moderates the severity of the cold. On the other hand, the melting or thawing of ice produces cold, which prevents the dreadful effects that might be occasioned by a too rapid thaw, especially when the ground is covered with a very deep snow.

The height above the level of the sea causes a diminution of heat at the rate of 1° for about 300 feet of elevation, which agrees with observations made for twelve years, at Highgate and Camden Town, the average temperature of the former place being one degree lower than that of the latter.

The varieties of temperature on the surface of the earth are probably confined between the limits of 100° above and 40° below 0, or zero.

No natural degree of cold much below this has been ever known; and the thermometer, in the shade, has rarely, if ever, been seen at 100°. In this country, as far as I have ascertained, the hottest day was Wednesday, July 13. 1808, when the mercury stood at 90° in an open situation in the neighbourhood of London; but in London and confined places it was still higher.

There is no doubt that the climates of Europe were more severe in ancient times than they now are, and the change is ascribed to the better cultivation of the soil. Cultivation may, in fact, improve a climate; first by draining marshes and low grounds, and thereby lessening the evaporation; secondly, by turning up the soil, and exposing it to the rays of the sun; and thirdly, by thinning or cutting down forests, which, by their shade, prevent the penetration of the sun's rays. The improvements that are taking place in the climate of North America prove that the power of man extends to phenomena which, from the magnitude and variety of their causes, appear beyond its reach.

The vapour that rises from water, uniting itself to the air, ascends into the higher regions of the atmosphere, and is often carried by the winds to great distances. It is chemically dissolved in the air.

Humidity does not lessen, but increases, the transparency of the air; hence we often have the clearest atmosphere the day before heavy rains. If two portions of air, of different temperatures, but both saturated with humidity, be mixed to-

gether, a precipitation must, on chemical principles, be thrown down in the shape of clouds or rain.

Dew is a precipitation of humidity from the lower strata of the atmosphere. When air containing humidity cools below a certain point, it must begin to deposit its moisture. In this way dew is formed in warm weather, when, on the sun's going down, the heat of the air at the surface is greatly diminished.

Meteoric stones have been the subject of much controversy. Some believe them to have been originally vomited forth from volcanoes. Others have fancied that they have been projected by volcanoes in the moon, beyond the sphere of the moon's attraction, and have in due course fallen to the earth. Others have thought that they owe their origin to the atmosphere; that the air is full of particles of foreign matter; and that lightning forms them into a mass. But there are many serious objections to these hypotheses. The most reasonable is the cosmical theory, which supposes them to be little masses of planetary matter revolving in space; and this is the more probable from the fact, that in August and November, when the earth is in the same parts of planetary space, they are periodically abundant; just as though the earth at that time came amongst a good group of them.

OPTICS.

CONVERSATION I.

INTRODUCTION.

Tutor — Charles — James.

Of Light. — Its Velocity. — Moves only in straight lines.

C. When we were on the sea, you told us that you would explain the reason why the oar, which was straight when it lay in the boat, appeared crooked as soon as it was put into the water.

T. I did; but it requires some previous knowledge before you can comprehend the subject. It would afford you but little satisfaction to be told that this deception was caused by the different degrees of *refraction* which take place in water and air.

J. We do not know what you mean by the word refraction.

T. It will therefore be right to proceed with caution. *Refraction* is a term frequently used in the science of optics, and this science depends wholly on *light.*

J. What is light?

T. It would perhaps be difficult to give a direct answer to your question, because we know nothing of the nature of light but by the effects which it produces.

J. Does not the light come from the sun in some such manner as it does from a candle?

T. This comparison will answer our purpose. But there appears to be a great difference between the two bodies. A candle, whether of wax or tallow, is soon exhausted; but philosophers have never been able to observe that the body of the sun is diminished by the light which it incessantly pours forth.

J. Pray, sir, how swiftly do you reckon that light moves?

T. This you will easily calculate when you know that it is only about eight minutes in coming from the sun to us.

C. And if you reckon the sun to be at the distance of ninety-five millions of miles from the earth, light proceeds at the rate, nearly, of twelve millions of miles in a minute, or 260,000 miles

in a second of time. But how do you know that it travels so fast?

T. It was discovered by M. Roemer, who observed that the eclipses of Jupiter's satellites took place about sixteen minutes later, if the earth were in that part of its orbit which is farthest from Jupiter, than if it were in the opposite point of the heavens.

C. I understand this; the earth may sometimes be in a line between the sun and Jupiter; and at other times the sun is between the earth and Jupiter; and therefore, in the latter case, the distance of Jupiter from the earth is greater than in the former, by the whole length of the diameter of the earth's orbit.

T. In this situation the eclipse of any of the satellites is by calculation sixteen minutes later than it would be if the earth were between Jupiter and the sun; that is, the light flowing from Jupiter's satellites is about sixteen minutes in travelling the width of the earth's orbit, or 190 millions of miles.

J. It would be curious to calculate, how much faster light travels than a cannon ball.

T. Suppose a cannon ball to travel at the rate of twelve miles a minute: light is calculated to move a million times faster than that; yet it is conjectured that there may be stars so distant from us that the light proceeding from them has not yet reached the earth.

C. And have I not heard you say that some of the smaller nebulæ are so far distant, that their light could not have reached us in less than many thousand years more than the vulgar notion of the duration of time?

T. Yes: and this is one of the strongest confirmations of the ideas put forth by geologists, that the mere earth existed, with a different organic creation, long before man was placed upon it.

J. And you say light moves in all directions?

T. Here is a sheet of thick brown paper, and I only make a small pin-hole in it, and then, through that hole, I can see the same objects, such as the sky, tree, houses, &c., as I could if the paper were not there.

C. Do we only see objects by means of the rays of light that flow from them?

T. In no other way, and therefore the light that comes from the landscape, which I view by looking through the small hole in the paper, must come in all directions at the same time. Take another instance: if a candle be placed on an eminence in a dark night, it may be seen all round for the space of half a

mile; in other words, there is no place within a sphere of a mile diameter, where the candle cannot be seen, that is, where some of the rays from the small flame will not be found.

J. Why do you limit the distance to half a mile?

T. The distance, of course, will be greater or less, according to the size of the candle; but the degree of light, like heat, diminishes in proportion as the square of the distance from the luminous body increases.

J. Do you mean that, at the distance of two yards from a candle, we shall have four times less light than we should have if we were only one yard from it?

T. I do: and at three yards' distance nine times less light; and at four yards' distance you will have sixteen times less light than you would were you within a yard of the object. I have one more thing to tell you: light always moves in straight lines.

J. How is that known?

T. Look through a straight tube at any object, and the rays of light will flow readily from it to the eye; but let the tube be bent, and the object cannot be seen through it, which proves that light will move only in a straight line.

This is plain also from the shadows which opaque bodies cast; for if the light did not describe straight lines, there would be no shadow. Hold any object in the light of the sun, or a candle, as a square board or book, and the shadow caused by it proves that light moves only in right or straight lines; for the space immediately behind the board or book is in shade.

C. Is it not dark there?

T. No, not *absolutely* dark: it is enlightened in some degree by rays reflected from the illuminated space.

CONVERSATION II.

Of Rays of Light. — Of Reflection and Refraction.

C. You talked, the last time we met, of the rays of light flowing or moving: what do you mean by a *ray of light?*

T. We must first think of what *light* itself is. It had long been maintained by philosophers, that it consisted of infinitely small particles, given off by the luminous body; but this theory is fast losing ground. It is the general opinion now, that light is the result of undulatory motions impressed upon the *something* or the *nothing*, which philosophers call the ether, that pervades space. So that a ray of light is very much analogous to

the wave of sound; the one, however, affecting the eye, the other the ear. Now light, — or more properly a right line extending from the luminous body to the limit of illumination — is about eight minutes in coming from the sun to us; then, if the sun were blotted from the heavens, we should actually have the same appearance for eight minutes after the destruction of that body as we now have.

J. I do not understand how we could see a thing that would not exist.

T. You do not? Throw a stone in the water, it is now at the bottom, and as a source of waves ceases to exist; but the last wave has not yet reached the shore. And so it is with light; the undulation, once given, must proceed on; but it does not follow that the light which caused the undulation should so act, as it were, until the wave reached a human eye. Remember, two things are necessary for the existence of light; an undulation, and an eye to receive it; if either of them is wanting, there is no light. A blind man has no idea of light; the best notion a certain blind man had of scarlet, after long teaching, was that it was like *the sound of a trumpet.*

C. Do we not actually see the body itself?

T. No: we see the light emanating from it, or reflected from it.

J. What do you mean by being *reflected?*

T. If I throw this marble smartly against the wainscot, will it remain where it was thrown?

J. No: it will *rebound*, or come back again.

T. What you call rebounding, writers on optics denominate *reflection.* When a body of any kind, whether it be a marble with which you play, or a wave of light, strikes against a surface and is sent back again, it is said to be reflected. If you shoot a marble straight against a board, or other obstacle, it comes back in the same line, or nearly so; but suppose you throw it sidewise, does it return to the hand?

C. Let me see: I will shoot this marble against the *middle* of one side of the room from the corner of the opposite side.

J. You perceive that, instead of coming back to your hand, it goes off to the other corner directly opposite to the place from which you sent it.

T. This will lead us to the explanation of one of the principal definitions in optics, — viz. *that the angle of reflection is always equal to the angle of incidence.* You know what an angle is? *

C. We do: but not what an angle of *incidence* is.

* See Conversation I.

T. I said a ray of light was a wave, or undulation: now there are *incident* rays and *reflected* rays.

The *incident* rays are those which *fall on* the surface; and the *reflected* rays are those which are *sent off* from it.

C. Does the line made or supposed to be made by the marble in *going to* the wainscot represent the *incident* ray, and in *going from* it does it represent the *reflected* ray?

T. It does; and the wainscot may be called the reflecting surface.

J. Then what are the angles of incidence and reflection?

T. Suppose you draw the lines on which the marble travelled, both to the wainscot and from it again.

C. I will do it with a piece of chalk as nearly as I can.

T. Now draw a perpendicular * from the point where the marble struck the surface, that is, where your two lines meet.

C. I see there are two angles, and they seem to be equal.

T. We cannot expect mathematical precision in such trials as these; but if the experiment were accurately made, with a perfectly elastic substance, the two angles would be perfectly equal: the angle contained between the incident ray and the perpendicular is called the angle of incidence, and that contained between the perpendicular and reflected ray is called the angle of reflection.

J. Are these in all cases equal, shoot the marble as you will?

T. They are; and the truth holds equally with the rays of light: — both of you stand in front of the looking-glass. You see yourselves, and one another also; for the rays of light flow from you to the glass, and are reflected back again in the same lines. Now both of you stand on one side of the room. What do you see?

C. Not ourselves, but the furniture on the opposite side.

T. The reason of this is, that the rays of light, flowing from you to the glass, are reflected to the other side of the room.

C. Then if I go to that part, I shall see the rays of light flowing from my brother; and I do see him in the glass.

J. And I see Charles.

T. Now the rays of light flow from each of you to the glass, and are reflected to one another: but neither of you sees himself.

C. No: I will move in front of the glass; now I see myself, but not my brother; and I think I understand the subject very well.

* If the point be exactly in the middle of one side of the room, a perpendicular is readily drawn by finding the middle of the opposite side, and joining the two points.

T. Then explain it to me by a figure, which you may draw on the slate.

C. Let A B represent the looking-glass: if I stand at C, the rays flow from me to the glass, and are reflected back in the same line, because now there is no angle of incidence, and of course no angle of reflection; but if I stand at *x*, then the rays flow from me to the glass, but they make the angle *x* O C, and therefore they must be reflected in the line O *y* so as to make the angle *y* O C, which is the angle of reflection, equal to the angle *x* O C. And if James stand at *y*, he will see me at *x*, and I standing at *x* shall see him at *y*.

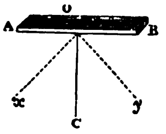


Fig. 1.

T. The same thing occurs with respect to every plane reflecting surface, as well as in a looking-glass; as in clear water, or in highly polished steel, mahogany, &c.

C. Are the undulations, which produce light, rapid?

T. Yes: 477 millions of millions of vibrations must occur in a second to produce red light; and 699 millions of millions to produce violet. The waves of light are minute beyond imagination. There are 39,180 waves or undulations of red light in an inch; and 57,490 of violet light, the extreme violet ray has 2260 more waves in an inch. Ask Emma to strike the middle C of her piano; now, if that string were bisected 40 times, and it were possible to make it vibrate, what would it produce?

E. A very inaudible sound, surely.

T. No: it would actually produce *yellowish-green light.*

CONVERSATION III.

Of the Refraction of Light.

C. If glass stop the rays of light, and reflect them, why cannot I see myself in the window?

T. It is the silvering on the glass which causes the reflection. No glass, however, is so transparent, but it reflects some rays: put your hand to within three or four inches of the window, and you see clearly the image of it.

J. So I do; and the nearer the hand is to the glass, the more evident the image; but it is formed on the other side of the glass, and beyond it too.

T. It is; this happens also in looking glasses; you do not see yourself on the surface, but apparently as far behind the glass as you stand from it in the front.

Whatever suffers the rays of light to pass through it, is called

a *medium.* Glass, which is transparent, is a medium; so also are air and water: and indeed all fluids that are transparent are called *media*, and the more transparent the body, the more perfect is the medium.

C. Do the rays of light pass through these in a straight line?

T. They do; but if they enter it at an angle they do not pass through in precisely the same direction in which they were moving, before they entered it. They are *bent* out of their former course, and this is called *refraction.*

J. Can you explain this term more clearly?

T. Suppose A B to be a piece of glass two or three inches thick, and a ray of light, s *a*, to fall upon it at *a*; it will not pass through in the direction s s, but when it comes to *a*, it will be bent towards the perpendicular *a b*, and go through the glass in the course *a x*; and when it comes into the air, it will pass on in the direction *x z*, which is parallel to s s.

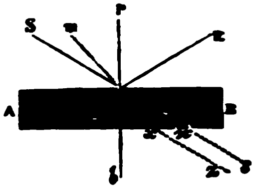


Fig. 2.

C. Does this happen if the ray fall perpendicularly on the glass at P *a*?

T. In that case there is no refraction, but the ray proceeds in its passage through the glass, precisely in the same direction as it did before it entered it, namely, in the direction P *b*.

J. Refraction, then, takes place only when the rays fall obliquely or slantwise on the medium?

T. Just so: rays of light may pass out of a rarer into a denser medium, as from air into water or glass; or they may pass from a denser medium into a rarer, as from water into air.

C. Are the effects the same in both cases?

T. They are not; and I wish you to remember the difference. When light passes out of a rarer into a denser medium, it is drawn to the perpendicular: thus if s *a* pass from air into glass, it moves, in its passage through it, in the line *a x*, which is nearer to the perpendicular P *b* than the line *a* s, which was its first direction.

But when a ray passes from a denser medium into a rarer, it moves in a direction *farther from* the perpendicular; thus if the ray *x a* pass through glass or water into air, it will not, when it comes to *a*, move in the direction *a m*, but in the line *a* s, which is farther than *a m* from the perpendicular *a* P.

J. Can you show us any experiment in proof of this?

T. Yes, I can: here is a common earthen pan, on the bottom

of which I will lay a shilling, and will fasten it with a piece of soft wax, so that it shall not move from its place, while I pour in some water. Stand back, till you just lose sight of the shilling.

J. The side of the pan now completely hides the sight of the money from me.

T. I will pour in a pitcher of clear water.

J. I now see the shilling; how is this to be explained?

T. Look to the last figure, and conceive your eye to be at s, *a b* the side of the pan, and the piece of money to be at *x*: now, when the pan is empty, the rays of light flow from *x*, in the direction *x a m*; but your eye is at s, of course you cannot see anything by the ray proceeding along *x a m*. As soon as I put the water into the vessel, the rays of light proceed from *x* to *a*, but there they enter from a denser to a rarer medium; and therefore, instead of moving in *a m*, as they did when there was no water, they will be bent *from* the perpendicular, and will come to your eye at s, as if the shilling were situate at *n*.

J. And it does appear to me to be at *n*.

T. Remember what I am going to tell you, for it is a sort of axiom in optics; "We see everything in the *direction* of that line of which the rays approach us last." Which may be thus illustrated: I place a candle before the looking-glass, and if you stand also before the glass, the image of the candle appears behind it; but if another looking-glass be so placed as to receive the reflected rays of the candle, and you stand before this second glass, the candle will appear behind that; because the mind transfers every object seen along the line in which the rays come to the eye last.

C. If the shilling were not moved by the pouring in of the water, I do not understand how we could see it afterwards.

T. But you do see it now at the point *n*, or rather at the little dot just above it, which is an inch or two from the place where it was fastened from the bottom, and from which, you may convince yourself, it has not moved.

J. I should like to be convinced of this. Will you make the experiment again, that I may be satisfied of it?

T. You may make it as often as you please, and the effect will always be the same; but you must not imagine that the shilling only will appear to move, the bottom of the vessel seems also to change its place.

J. It appears to me to be raised higher as the water is poured in.

T. I trust you are satisfied by this experiment; but I can

show you another equally convincing; but for this we stand in need of the sun.

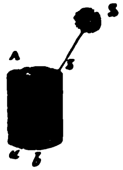


Fig. 2.

Take an empty vessel, A, a common pan or basin will answer the purpose, into a dark room, having only a very small hole in the window-shutter; so place the basin that a ray of light *s s* shall fall upon the bottom of it at *a*; here I make a small mark, and then fill the basin with water. Now where does the ray fall?

J. Much nearer to the side at *b*.

T. I did not move the basin, and therefore could have had no power in altering the course of the light.

C. It is very clear that the ray was refracted by the water at *s*, and I see that the effect of refraction, in this instance, has been to draw the ray nearer to a perpendicular, which may be conceived to be the side of the vessel.

T. The same thing may be shown with a candle in a room otherwise dark. Let it stand in such a manner as that the shadow of the side of a pan or box may fall somewhere at the bottom of it; mark the place, and pour in water, and the shadow will not then fall so far from the side. For in this case, the rays of light pass *out of air*, which is a rare medium, *into water*, which is a denser medium, and are accordingly drawn nearer to the perpendicular.

J. Do all media refract equally?

T. No. There is a great difference in the *refracting index*, as it is termed, of bodies. Vacuum being reckoned as 1·0,—

Hydrogen is - - - -	1·00013
Ice „ - - - -	1·309
Water „ - - - -	1·336
Alcohol „ - - - -	1·372
Flint-glass „ - - - -	1·60
Diamond „ - - - -	1·439

These numbers refer to a certain trigonometrical relation existing between the angle of incidence, s *a* A, and the angle of reflection, x *a b*, fig. 2. The absolute refracting power estimated in proportion to the specific gravity of bodies is found greatest in combustible bodies.

Hydrogen - - - - -	3·095
Water - - - - -	·7845
Alcohol - - - - -	1·0121
Flint-glass - - - - -	·7986
Diamond - - - - -	1·4866

And this it was which led Sir Isaac Newton to suspect that diamond was a combustible body, which experiment has now demonstrated. It is carbon, or charcoal.

CONVERSATION IV.

Of the Reflection and Refraction of Light.

T. We will now proceed to some farther illustrations of the laws of reflection and refraction. We shut out all the light except the ray that comes in at the small hole in the shutter. At the bottom of this basin, where the ray of light falls, I lay this piece of looking-glass; and if the water be rendered in a small degree opaque by mixing with it a few drops of milk, and the room be filled with dust by sweeping a carpet, or any other means, then you will see the refraction which the ray from the shutter undergoes in passing into the water, the reflection of it at the surface of the looking-glass, and the refraction which takes places when the ray leaves the water, and passes again into the air.

J. Does this refraction take place in all kinds of glass?

T. It does; but where the glass is very thin, as in window glass, the deviation is so small as to be generally overlooked. You may now understand why the oar in the water appears bent, though it be really straight; for suppose A B represent water, and *m a x* the oar; the image of the part *a z* in the water will lie above the object, so that the oar will appear in the shape *m a n*, instead of *m a z*. On this account, also, a fish in the water appears nearer the surface than it actually is, and a marksman shooting at it must aim below the place which it seems to occupy.

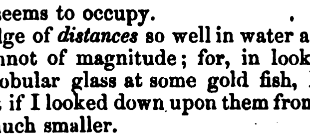


Fig. 4.

C. I see that we cannot judge of *distances* so well in water as in air. And I am sure we cannot of magnitude; for, in looking through the sides of a globular glass at some gold fish, I thought them very large; but if I looked down upon them from the top, they appeared very much smaller.

T. Here the convex or round shape of the glass becomes a magnifier, the reason of which will be explained hereafter. A fish will, however, look larger in water than it really is. I will show you another experiment, which depends on refraction. Here is a glass goblet two-thirds full of water; I throw into it

a shilling, and place a plate on the top of it, and turn it quickly over, that the water may not escape. What do you see?

C. There seems certainly a half-crown lying on the plate, and a shilling appears to be swimming above it in the water.

T. So it seems, indeed; but it is a deception, which arises from your seeing the piece of money in two directions at once, viz., through the conical surface of the water at the side of the glass, and through the flat surface at the top of the water. The conical surface, as was the case with the globular one in which the fish were swimming, magnifies the money; but by the flat surface the rays are only refracted, on which account the money is seen higher up in the glass, and of its natural size, or nearly so.

J. If I look sidewise at the money, I only see the large piece; and, if only at top, I see it in its natural size and state.

C. Look again at the fish in the glass, and you will see through the round part two very large fish, and seeing them from the upper part, they appear of their natural size; the deception is the same as with the shilling in the goblet.

T. The principle of refraction is productive of some very important effects. By this the sun, every clear morning, is seen several minutes before he comes to the horizon, and as long after he sinks beneath it in the evening.

C. Then the days are longer than they would be, if there was no such a thing as refraction. Will you explain how this happens?

T. I will. You know we are surrounded with an atmosphere of sufficient density to refract the rays of light, extending to above the height of forty-five miles. Now the dotted part of this diagram represents that atmosphere. Suppose a spectator stand at s, and the sun to be at *a*; if there were no refraction, the person at s would not see the rays of the sun till he were situate with regard to the sun in a line s *x a*; because, when it was below the horizon, at *b*, the rays would pass by the earth in the direction *b x z*; but, owing to the atmosphere and its refracting power, when the rays from *b* reach *x*, they are bent towards the perpendicular, and carried to the spectator at s.

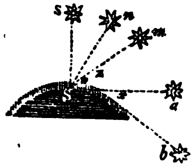


Fig. 5.

J. Will he really see the image of the sun while it is below the horizon?

T. He will; for it is easy to calculate the moment when the sun should rise and set, and, if that be compared with exact observation, it will be found that the image of the sun is seen sooner or later than this, by several minutes every clear day.

C. Are we subject to the same kind of deception when the sun is actually above the horizon?

T. We are always subject to it in these latitudes, for the sun is never in that place in the heavens where he appears to be.

J. Why in these latitudes particularly?

T. Because with us the sun is never in the *zenith*, s, or directly over our heads; and in that situation alone his *true* place in the heavens is the same as his *apparent* place.

C. Is that because there is no refraction when the rays fall perpendicularly on the atmosphere?

T. It is; but when the sun is at *m*, in the last figure, his rays will not proceed in a direct line *m o* s, but will be bent out of their course at *o*, and go in the direction *o* s, and the spectator will imagine he sees the sun in the line of s *o n*.

C. What makes the moon look so much larger, when it is just above the horizon, than when it is higher up.

T. The thickness of the atmosphere, when the moon is near the horizon, renders it less bright than when it is higher up, which leads us to suppose it is farther off in the former case than in the latter; and, because we imagine it to be farther from us, we take it to be a larger object than when it is higher.

It is owing to the atmosphere that the heavens appear bright in the daytime. Without any atmosphere only that part of the heavens would appear luminous in which the sun is seen; in that case, if we could live without air, and should stand with our backs to the sun, the whole heavens would appear as dark as night. We cannot, therefore, too highly estimate the importance of an atmosphere that affords those reflections and refractions of light, which shed lustre over surrounding objects, and which form pleasing transitions from darkness to day, and from day to night, by means of twilight.

The particles of light from the sun travel in immense regions of complete darkness, till they arrive at the atmospheres of the several planets and satellites, when their passage through those atmospheres, by direct motion, reflection, and refraction, gives occasion to the manifestation of light, and all its beauteous, striking, and useful modifications.

CONVERSATION V.

Definitions—Of the different kinds of Lenses—Of Mr. Parker's Burning Lens, and the effects produced by it.

T. I must claim your attention to a few other definitions; the knowledge of which will be wanted as we proceed.

A pencil of rays is any number that proceed from a point.

Parallel rays are such as always move at the same distance from each other.

C. That is something like the definition of *parallel lines.** But, when you admitted the rays of light through the small hole in the shutter, they did not seem to flow from that point in parallel lines, but to recede from each other in proportion to their distance from that point.

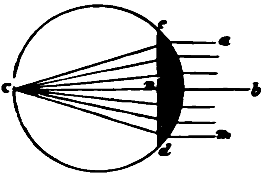


Fig. 6.

T. They did; and when they do thus recede from each other, as in this figure, from c to *c d*, then they are said to *diverge*. But if they continually approach towards each other, as in moving from *c d* to c, they are said to *converge*.

J. What does the dark part of this figure represent?

T. It represents a glass lens, of which there are several kinds.

C. How do you describe a lens?

T. A *lens* is a glass ground into such a form as to collect or disperse the rays of light which pass through it. Lenses are of different shapes, from which they take their names. They are represented here in one view. A is such a one as that in the

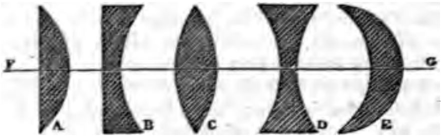


Fig. 7.

last figure, and it is called a *plano-convex*, because one side is flat and the other convex; B is a *plano-concave*,—one side being *flat*, and the other *concave;* C is a *double convex lens*, because both sides are convex; D is a *double concave*, because both sides are concave; and E is called a *meniscus*, being convex on one side, and concave on the other; of this kind are all watch glasses.

J. I can easily conceive diverging rays, or rays proceeding from a point; but what is to make them converge, or come to a point?

T. Look again to fig. 6.; now *a b m*, &c. represent parallel

* Parallel lines are those which, being infinitely extended, never meet.

rays, falling upon *c d*, a convex surface, of glass, for instance, all of which, except the middle one, fall upon it obliquely, and, according to what we saw yesterday, will be refracted towards the perpendicular.

C. And I suppose they will all meet in a certain point in that middle line.

T. That point c is called the *focus*: the dark part only of this figure represents the glass, as *c d n*.

C. Have you drawn the circle to show the exact curve of the different lenses?

T. Yes: and you see that parallel rays falling upon a *plano-convex lens* meet at a point behind it, the distance of which, from the middle of the glass, is exactly equal to the diameter of the sphere of which the lens is a portion.

J. And in the case of a *double convex*, is the distance of the focus of parallel rays equal only to the radius of the sphere?

T. It is; and you see the reason of it immediately; for two concave surfaces have double the effect in refracting rays to what a single one has: the *latter* bringing them to a focus at the distance of the diameter, the former at half that distance, or the radius.

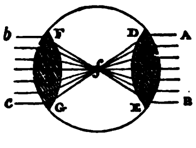


Fig. 8.

C. Sometimes, perhaps, the two sides of the same lens may have different curves: what is to be done then?

T. If you know the radius of both the curves, the following rule will give you the answer:

"As the sum of the radii of both curves or convexities is to the radius of either, so is double the radius of the other to the distance of the focus from the middle point."

J. Then if one radius be four inches, and the other three inches, I say, as $4 + 3 : 4 :: 6 : \frac{24}{7} = 3\frac{3}{7}$, or to nearly three inches and a half.

I saw an old sailor lighting his pipe yesterday by means of the sun's rays and a glass: was that a double convex lens?

T. I dare say it was; and you now see the reason of that which then you could not comprehend: all the rays of the sun that fall on the surface of the glass in the last figure are collected in the point *f*, which, in this case, may represent the tobacco in the pipe.

C. How do you calculate the heat which is collected in the focus?

T. The force of the heat collected in the focus is in proportion to the common heat of the sun, as the area of the glass is

to the area of the focus: of course, it may be a hundred or even a thousand times greater in the one case than in the other.

J. Have I not heard you say that Mr. Parker, of Fleet Street, made once a very large lens, which he used as a burning-glass?

T. He formed one three feet in diameter, and when fixed in its frame, it exposed a clear surface of more than two feet eight inches in diameter, and its focus, by means of another lens, was reduced to a diameter of half an inch. The heat produced by this was so great, that iron plates were melted in a few seconds; tiles and slates became red-hot in a moment, and were vitrified, or changed into glass; sulphur, pitch and other resinous bodies, were melted under water: wood ashes, and those of other vegetable substances, were turned in a moment into transparent glass.

C. Would the heat produced by it melt all the metals?

T. It would: even gold was rendered fluid in a few seconds: notwithstanding, however, this intense heat at the focus, the finger might, without the smallest injury, be placed in the cone of rays within an inch of the focus.

J. There was, however, I should suppose, some risk in this experiment, for fear of bringing the finger too near the focus?

T. Mr. Parker's curiosity led him to try what the sensation would be at the focus; and he describes it like that produced by a sharp lancet, and not at all similar to the pain produced by the heat of fire or a candle. Substances of a white colour were difficult to be acted upon.

C. I suppose he could cause water to boil in a very short time with the lens?

T. If the water be very pure, and contained in a clear glass decanter, it will not be warmed by the most powerful lens. But a piece of wood may be burned to a coal, when it is contained in a decanter of water.

J. Will not the heat break the glass?

T. It will scarcely warm it; if, however, a piece of metal be put in the water, and the point of rays be thrown on that, it will communicate heat to the water, and sometimes make it boil. The same effect will be produced if there be some ink thrown into the water.

If a cavity be made in a piece of charcoal, and the substance to be acted on be put in it, the effect produced by the lens will be much increased. Any metal thus inclosed melts in a moment, the fire sparkling like that of a forge to which the blast of a bellows is applied.

C. Cannot the same effects be produced by a concave mirror?

T. Every concave mirror, or speculum, whether made of glass or metal, collects the rays, dispersed through the whole concavity,

after reflection, into a point or focus, and is therefore a burning mirror.

The ancients made use of concave mirrors to rekindle the Vestal fires. Plutarch says, that they employed for that purpose σκαφεῖα or dishes. They were, most probably, hollow hemispherical vessels, finely polished within. Such vessels, placed opposite the sun, would collect its rays into a focus, at half the radius; where the Vestal virgins holding the combustible matter, for a short time, would bring it away burning.

CONVERSATION VI.

Of Parallel Rays — Of Diverging and Converging Rays — Of the Focus and Focal Distances.

C. I have been looking at the figures 6 and 8, and see that the rays falling upon the lenses are parallel to one another; are the sun's rays parallel?

T. They are considered so; but you must not suppose that all the rays that come from the surface of an object, as the sun, or any other body, to the eye, are parallel to each other, but it must be understood of those rays only which proceed from a single point. Suppose S to be the sun, the rays which proceed from a single point A do in reality form a cone, the *base* of which is the pupil of the eye, and its height is the distance from us to the sun.

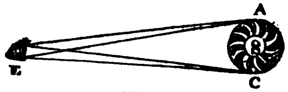


Fig. 9.

But the breadth of the eye is nothing when compared to a line ninety-five millions of miles long.

If now we take a ray from the point A, and another from C, on opposite points of the sun's disc, they will form a sensible angle at the eye; and it is from this angle A E C that we judge of the apparent size of the sun.

J. If there be nothing to receive the rays (Fig. 8.) at *f*, would they cross one another and diverge?

T. Certainly, in the same manner as they converge in coming to it; and if another glass, F G, of the same convexity as D E, be placed in the rays at the same distance from the focus, it will so refract them that, after going out of it, they will be parallel, and so proceed on in the same manner as they came to the first glass.

C. There is, however, this difference; all the rays, except the middle one, have changed sides.

T. You are right; the ray B, which entered at bottom, goes

out at the top *b*; and A, which entered at the top, goes out at the bottom *c*, and so of the rest.

If a candle be placed at *f*, the focus of the convex glass, the diverging rays in the space F *f* G, will be so refracted by the glass that after going out of it, they will become parallel again.

J. What will be the effect if the candle be nearer to the glass than the point *f*?

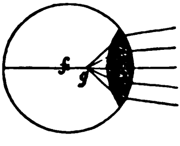


Fig. 10.

T. In that case, as if the candle be at *g*, the rays will diverge after they have passed through the glass, and the divergency will be greater or less in proportion as the candle is more or less distant from the focus.

C. If the candle be placed farther from the lens than the focus *f*, will the rays meet in a point after they have passed through it?

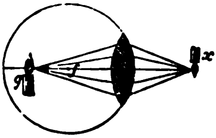


Fig. 11.

T. They will: thus, if the candle be placed at *g*, the rays, after passing the lens, will meet at *x*; and this point *x* will be *more* or less distant from the glass, as the candle is *nearer* to, or farther from its focus. Where the rays meet, they form an *inverted* image of the flame of the candle.

J. Why so?

T. Because that is the point where the rays, if they are not stopped, cross each other: to satisfy you on this head, I will hold in that point a sheet of paper, and you now see that the flame of the candle is inverted.

J. How is this explained?

T. Let A B C represent an arrow placed beyond the focus F, of a double convex lens *d e f*, some rays will flow from every part of the arrow, and fall on the lens; but we shall consider only those which flow from the points A B and C. The rays which come from A, as A *d*, A *e*, and A *f*, will be refracted by the lens, and meet in A; those which come from B, as B *d*, B *e*, and B *f*, will unite in *b*; and those which come from C will unite in C.

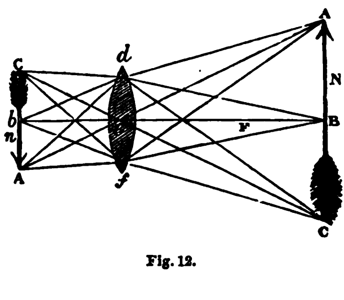


Fig. 12.

C. I see clearly how the rays from B are refracted and unite in *b*; but it is not so evident with regard to those from the extremities A and C.

T. I admit it; but you must remember the difficulty consists in this, the rays fall more obliquely on the glass from those points than from the middle, and therefore the refraction is very different. The ray B F in the centre suffers no refraction, B *d* is refracted into *b*, and if another ray went from N, as N *d*, it would be refracted to *n*, somewhere between *b* and *a*, and the rays from A must, for the same reason, be refracted to *a*.

J. If the object A B C is brought nearer to the glass, will the picture be removed to a greater distance?

T. It will: for then the rays will fall more diverging upon the glass, and cannot be so soon collected into the corresponding points behind it.

C. From what you have said, I see that if the object A B C be placed in F, the rays, after refraction, will go out parallel to one another; and if brought nearer to the glass than F, then they will diverge from one another, so that in neither case will an image be formed behind the lens.

CONVERSATION VII.

Images of Objects inverted—Of the Scioptric Ball—Of Lenses and their Foci.

J. Will the image of a candle, when received through a convex lens, be inverted?

T. It will, as you shall see. Here is no light in this room but from the candle, the rays of which pass through a convex lens, and, by holding a sheet of paper in a proper place, you will see a complete inverted image of the candle on it.

An object seen through a very small aperture appears also inverted; but it is very imperfect compared to an image formed with a lens; it is *faint* for want of light, and it is *confused* because the rays interfere with one another.

C. What is the reason of its being inverted?

T. Because the rays from the extreme parts of the object must cross at the hole. If you look through a very small hole at any object, the object appears magnified. Make a pin-hole in a sheet of brown paper, and look through it at the small print of this book.

J. It is, indeed, very much magnified.

T. As an object approaches a convex lens, its image departs from it; and as the object recedes, its image advances. Make

he experiment with a candle and a lens, properly mounted, in a long room. When you stand at one end of the room, and throw the image on the opposite wall, the image is large, but as you come nearer to the wall the image is small, and the distance between the candle and glass is very much inereased.

I will now show you an instrument called a *Scioptric Ball*, which is fastened into a window-shutter of a room from which all light is excluded except what comes in through this glass.

C. Of what does this instrument consist?

Fig. 13.

T. Of a frame A B and a ball of wood C, in which is a glass lens; and the ball moves easily in the frame in all directions, so that the view of any surrounding objects may be received through it. This instrument is sometimes called an artificial eye. Well, we will now place the screen properly, and turn the ball to the garden. Here you see all the objects perfectly expressed, but they are all inverted.

C. You have shown us in what manner the rays of light are refracted by convex lenses, when those rays are parallel. Will there not be a difference if the rays *converge* or *diverge* before they enter the lens?

T. Certainly. If rays *converge* before they enter a convex lens, they will be collected at a point *nearer* to the lens than the focus of parallel rays. But if they *diverge* before they enter the lens, they will then be collected in a point *beyond* the focus of parallel rays. — There are concave lenses as well as convex, and the refraction which takes place by means of these differs from that which I have already explained.

C. What will the effect of refraction be, when parallel rays fall upon a double concave lens?

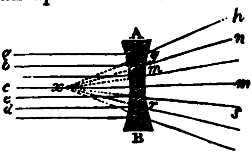


Fig. 14.

T. Suppose the parallel rays *a b c d*, &c., pass through the lens A B, they will *diverge* after they have passed through the glass.

J. Is there any rule for ascertaining the degree of divergency?

T. Yes, it will be precisely so much as if the rays had come from a radiant point *x*, which is the centre of the cavity of the glass.

C. Is that point called the focus?

T. It is called the *virtual* or *imaginary* focus.

J. Suppose the lens had been concave only on one side, and the other side had been flat; how would the rays have diverged?

T. They would have diverged after passing through it, as if

they had come from a radiant point at the distance of a whole diameter of the convexity of the lens.

C. There is, then, a great similarity in the refraction of the convex and concave lens.

T. True; the *focus* of a double convex is at the distance of the radius of convexity, and so is the *imaginary focus* of the double concave; and the *focus* of the plano-convex is at the distance of the diameter of the convexity, and so is the *imaginary focus* of the plano-concave.

You will find that images formed by a concave lens, or those formed by a convex lens, where the object is *within* its principal focus, are in the same position with the objects they represent; they are also *imaginary*, for the refracted rays never meet at the foci when they seem to diverge.

But the images of objects placed beyond the focus of a convex lens are inverted and *real;* for the refracted rays do meet at their proper foci.

Do not forget that the effect of convex lenses is to render the rays that pass through them convergent, and to bring them together into a focus. The effect of concave lenses is to render the rays transmitted through them more divergent.

CONVERSATION VIII.

Of the Nature and Advantages of Light.— Of the Separation of the Rays of Light by means of a Prism.— And of Compounded Rays, &c.

T. We cannot contemplate the nature of light without being struck with the great advantages which we enjoy from it. Without that blessing our condition would be truly deplorable.

"How," says a good writer, "could we provide ourselves with food, and the other necessaries of life? How could we transact the least business? How could we correspond with each other, or be of the least reciprocal service, without light, and those admirable organs of the body, which the Omnipotent Creator has adapted to the perception of this inestimable benefit?"

J. But you have told us that the light would be of comparatively small advantage without an atmosphere.

T. The atmosphere not only *refracts* the rays of light, so that we enjoy longer days than we should without it, but occasions that twilight which is so beneficial to our eyes; for without it the appearance and disappearance of the sun would have been instantaneous; and we should have experienced a sudden tran-

sition from the brightest sunshine to the most profound darkness, and from thick darkness to a blaze of light. The atmosphere reflects also the light in every direction; and if there were no atmosphere, the sun would benefit those only who looked towards it, while, to those whose backs were turned to that luminary, all would be darkness. Ought we not therefore gratefully to acknowledge the wisdom and goodness of the Creator, who has adapted these things to the advantage of his creatures?

J. I saw in some of your experiments that the rays of light, after passing through the glass, were tinged with different colours; what is the reason of this?

T. Formerly, light was supposed to be a simple and uncompounded body; Sir Isaac Newton, however, discovered that it was not a simple substance, but was composed of several parts, each of which has, in fact, a different degree of refrangibility.

C. How is that shown?

T. Let the room be darkened, and let there be only a very small hole in the shutter to admit the sun's rays: instead of a lens I take a triangular piece of glass, called a *prism*; now, as in this there is nothing to bring the rays to a focus, they will, in passing through it, suffer different degrees of refraction, and be separated into the different coloured rays, which, being received on a sheet of white paper, will exhibit the seven following colours, *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*.

J. Here are all the colours of the rainbow: the image on the paper is a sort of oblong.

T. That oblong image is usually called a *spectrum*; and if it be obtained by a flint glass prism, and divided into 360 equal parts, the red will occupy 56 of them, the orange 27, the yellow 27, the green 46, the blue 48, the indigo 47, and the violet 109.

These colours depend on the number of undulations in a given time or a given space. Sir John Herschel has detected a band of light beyond the violet; it is scarcely luminous; he calls it the *lavender* band. It is almost *dark light*; indeed, some philosophers have recognised the existence of dark light beyond the spectrum by its action on chemical bodies.

C. The shade of difference in some of these colours seems very small indeed.

T. You are not the only person who has made this observation: some experimental philosophers say there are but three original and truly distinct colours, viz. the *red*, *yellow*, and *blue*.

C. What is called the *orange* is surely only a mixture of the red and yellow, between which it is situated.

T. In like manner the *green* is said to be a mixture of the

yellow and blue, and the *violet* is but a fainter tinge of the indigo.

J. How is it then that light, which consists of different colours, is usually seen as white?

T. By mixing the several colours in due proportion, white may be produced.

J. Do you mean to say that a mixture of red, orange, yellow, green, blue, indigo, and violet, in any proportion, will produce a white?

T. If you divide a circular surface into 360 parts, and then paint it in the proportion just mentioned, that is, 56 of the parts red, 27 orange, 27 yellow, &c., and turn it round with great velocity, the whole will appear of a dirty white; and, if the colours were more perfect, the white would be so too.

J. Was it then owing to the separation of the different rays, that I saw the rainbow colours about the edges of the image made with the lens?

T. It was: some of the rays were scattered, and not brought to a focus, and these were divided in the course of refraction. And I may tell you now, though I shall not explain it at present, that the rainbow in the heavens is caused by the separation of the rays of light into their component parts.

CONVERSATION IX.

Of Colours.

C. After what you said yesterday, I am at a loss to know the cause of different colours: the cloth on this table is green; that of which my coat is made is blue: what makes the difference in these?

T. All colours are supposed to exist only in the light of luminous bodies, such as the sun, a candle, &c., and that light falling upon different bodies is separated into its seven primitive colours, some of which are absorbed, while others are reflected.

J. Is it from the reflected rays that we judge of the colour of objects?

T. It has generally been thought so; thus the cloth on the table absorbs all the undulations but those which produce green light, which it reflects to the eye; but your coat is of a different texture, and absorbs all but the blue rays.

C. Why is paper and the snow white?

T. The whiteness of paper is occasioned by its reflecting the greatest part of all the light that falls upon it. And every

flake of snow, being an assemblage of frozen globules of water sticking together, reflects and refracts the light that falls upon it in all directions, so as to mix it very intimately, and produce a white image on the eye.

J. Does the whiteness of the sun's light arise from a mixture of all the primary colours?

T. It does, as may be easily proved by an experiment; for if any of the seven colours be intercepted at the lens, the image in a great measure loses its whiteness. With the prism I will divide the ray into its seven colours*; I will then take a convex lens, in order to reunite them into a single ray, which will exhibit a round image of shining white; but if only five or six of these rays be taken with the lens, it will produce a dusky white.

J. The diamond, I know, owes its brilliancy to the power of reflecting almost all the rays of light that fall on it: but are vegetable and animal tribes equally indebted to it?

T. What does the gardener do to make his endive and lettuces white?

C. He ties them up.

T. That is, he shuts out the light, and by these means they become blanched. I could produce you a thousand instances to show, not only that the colour, but even the existence of vegetables, depends upon light. Close wooded trees have leaves on the outside only; such is the cedar in the garden. Look up the inside of a yew tree, and you will see that the inner branches are almost, or altogether, barren of leaves. Geraniums and other greenhouse plants turn their flowers to the light; and plants in general, if doomed to darkness, soon sicken and die.

J. There are some flowers, the petals of which are, in different parts, of different colours; how do you account for this?

T. The flower of the heart's-ease is of this kind; and, if examined with a good microscope, it will be found that the *texture* of the blue and yellow parts is very different. The texture of the leaves of the white and red rose is also different. Clouds also, which are so various in their colours, are undoubtedly more or less dense, as well as being differently placed with regard to the eye of the spectator; but they all depend on the light of the sun for their beauty.

C. Are we to understand that all colours depend on the reflection of the several coloured rays of light?

T. This seems to have been the opinion of Sir Isaac Newton;

* A figure will be given on this subject, with explanations, Conversation XVIII., on the Rainbow.

but he concluded, from various experiments on this subject, that every substance in nature, provided it be reduced to a proper degree of thinness, is transparent. Many transparent media reflect one colour and transmit another: gold-leaf reflects the yellow, but it transmits a sort of green colour by holding it up against a strong light.

When rays passing through a narrow slit are examined by a prism, the spectrum is traversed by numerous dark lines: each star, the sun, the planets, and artificial light, have their own systems of dark lines: it is supposed that some of the undulations are lost or checked. They are often called Fraunhofer's bands, from a philosopher who has greatly studied them.

J. Two interfering waves of water produce stillness: you have shown us that two interfering waves of sound produce silence: do two interfering undulations of light produce *darkness?*

T. Yes; and this may readily be shown. If two pieces of glass from the same plate are inclined on each other, and illuminated with a monochromatic or one-coloured light, there will be a series of alternate dark and one-coloured bands; the dark arise from the interference of two waves. If a pin or any small body is made to intercept rays in a dark box, it will be fringed with colours; in this case the undulations passing on one side of the pin, interfere with those on the other, and produce the spectral colours. Immediately under the pin is a dot of white light; for the undulations on each side here combine. If a disc having a small hole be placed in the path, the undulations interfere in such a manner as to produce a dark spot under the hole; in the one case darkness is changed to light, and in the other light to darkness. The colours of soap-bubbles depend on the same; the undulations from the one surface interfere with those from the other, and the retardation produced gives rise to the varieties of colours. The best mode of making a soap-bubble is to take a 6-ounce phial, one-third filled with water, and containing a piece of soap the size of a pea, place it in a vessel of hot water till it boils, and then suddenly cork it; remove it, and seal it. By this means most of the air is removed, and a gentle shake will produce a film that will remain for hours. If a lens is pressed on a plate of glass, a series of circular coloured rings, known as Newton's rings, will be seen: they are due to the same law of interference. Both these and the colour of soap-bubbles are one colour when looked *at*, and its complementary when looked *through*. The centre is *black* when looked *at*, and white when looked *through*. The thickness of the film of air to produce black when looked

at is half a millionth of an inch; of the film of water in the soap-bubble, one-fifth of a millionth.

C. I observe that there are several sets of colours in this soap-film; somewhat like so many rainbows following each other, and each different.

T. By observing these colours, and referring to tables calculated by Sir Isaac Newton, you will obtain the thicknesses of the film at each part. For instance, the red that is nearest the black is *nine* millionths of an inch thick. The next red is *eighteen and a third*; the next *thirty-two*; the next, *forty and a third*; the next, *fifty-two and a half*; and the next, *sixty-five*; and they all differ a little from each other.

You would find similar differences by following a set of any other colour.

The tints of mother of pearl are due to similar causes.

CONVERSATION X.

Reflected Light, and Plane Mirrors.

T. We now propose to speak of a different species of glasses, viz. of *mirrors*, or, as they are sometimes called, specula.

J. A looking-glass is a mirror, is it not?

T. Mirrors are made of glass silvered on one side; they are also made of highly polished metal. There are three kinds of mirrors, the *plane*, the *convex*, and the *concave*.

C. You have shown us that in a looking-glass, or plane mirror, "the angle of reflection is always equal to the angle of incidence." *

T. This rule is not only applicable to plane mirrors, but to those which are convex and concave also, as I shall show you to-morrow. But I wish to make some observations first on plane mirrors. In the first place, if you wish to see the complete image of yourself in a plane mirror or looking-glass, it must be *half* as long as you are high.

J. I should have imagined the glass must have been as long as I am high.

T. In looking at your image in the glass, does it not seem to be as far behind the glass as you stand before it?

J. Yes; and if I move forwards or backwards, the image behind the glass seems to approach or recede.

T. Let *a b* be the looking-glass, and A the spectator, standing

* See Conversation II.

opposite to it. The ray from his eye will be reflected in the same line *a* A, but the ray C *b* flowing from his foot, in order to be seen at the eye, must be reflected by the line *b* A.

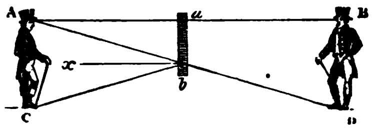


Fig. 15.

C. So it will; for if *x b* be a line perpendicular to the glass, the incident angle will be C *b x*, equal to the reflected angle A *b x*.

T. And therefore the foot will appear behind the glass at D along the line A *b* D, because that is the line in which the ray last approaches the eye.

J. Is that part of the glass *a b* intercepted by the lines A B and A D equal exactly to half the length B D or A C?

T. It is: A *a b* and A B D may be supposed to form two triangles, the sides of which always bear a fixed proportion to one another; and, if A B is double A *a*, as in this case it is, B D will be double *a b*, or at least of that part of the glass intercepted by A B and A D.

J. If I look at the reflection of a candle in a looking-glass, I see in fact two images, one much fainter than the other: what is the reason of this?

T. The reason of the double image is, that a part of the rays are immediately reflected from the upper surface of the glass, which form the faint image, while the greater part of them are reflected from the farther surface, or silvering part, and form the vivid image. To see these two images you must stand a little sideways, and not directly before the glass.

C. What is meant by the expression of "an image being formed behind a reflector?"

T. It is intended to denote that the reflected rays come to the eye with the same inclination as if the object itself were actually behind the reflector. If you, standing on one side of the room, see the image of your brother, who is on the other side, in the looking-glass, the image seems to be formed behind the glass; that is, the rays come to your eye precisely in the same way as they would if your brother himself stood in that place without the intervention of a glass.

J. But the image in the glass is not so bright or vivid as the object.

T. A plane mirror is in theory supposed to reflect all the

light which falls upon it, but in practice nearly half the light is lost, on account of the inaccuracy of the polish, &c.

C. Has it not been said that Archimedes, at the siege of Syracuse, burned the ships of Marcellus by a machine composed of mirrors?

T. Yes: but we have no certain accounts that may be implicitly relied on. M. Buffon, about eighty or ninety years ago, burned a plank at the distance of seventy feet, with forty plane mirrors.

J. I do not see how they can act as burning-glasses.

T. A plane mirror reflects the light and heat coming from the sun, and will illuminate and heat any substance on which they are thrown, in the same manner as if the sun shone upon it. Two mirrors will reflect on it a double quantity of heat; and if 40 or 100 mirrors could be so placed as to reflect from each the heat coming from the sun on any particular substance, they would increase the heat 40 or 100 times. In some such way as this, probably, Archimedes' mirrors were disposed. It is generally imagined that they were placed so as to fall in the interior surface of a paraboloid; but M. Peyrard, in his edition of the works of Archimedes, proves that this could not well be the case.

CONVERSATION XI.

Of Concave Mirrors—Their Uses—How they act.

J. To what uses are concave mirrors applied?

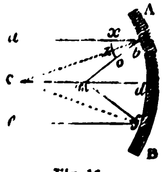


Fig. 10.

T. They are chiefly used in reflecting telescopes. A B represents a concave mirror, and *a b*, c *d*, *e f*, three parallel rays of light falling upon it. c is the centre of concavity; that is, one leg of your compasses being placed on c, and then opening them to the length c *d*, the other leg will touch the mirror A B in all its parts.

J. Then all the lines drawn from c to the glass will be equal to one another, as c *b*, c *d*, and c *f*?

T. They will: and there is another property belonging to them; they are all perpendicular to the glass in the parts where they touch.

c *d* is an *incident* ray, but as it passes through the centre of concavity, it will be reflected back in the same line; *a b* is an *incident* ray, and I want to know what will be the direction of the reflected ray?

C. Since c *b* is perpendicular to the glass at *b*, the angle of incidence is *a b* c; and as the angle of reflection is always equal to the angle of incidence, I must take another angle, as c *b m*, equal to *a b* c, and then the line *b m* is that in which the incident ray will move after reflection.

T. Can you, James, tell me how to find the line in which the incident ray *e f* will move after reflection?

J. Yes: I will make the angle c *f m* equal to c *f e*, and the line *f m* will be that in which the reflected ray will move; and I perceive that *e f* is reflected to the same point *m* as *a b* was.

T. If, instead of two incident rays, any number were drawn parallel to c *d*, they would every one be reflected to the same point *m*, provided the distance *b f* is not too large; and that point which is called the *focus of parallel rays* is distant from the mirror equal to half the radius c *d*.

J. Then we may easily find the point without the trouble of drawing the angles, merely by dividing the radius of concavity into two equal parts.

T. You may. The rays, as we have already observed, which proceed from any point of a celestial object, may be esteemed parallel at the earth, and therefore the image of that point will be formed at *m*.

C. Do you mean that all the rays flowing from a point of a star, and falling upon such a mirror, will be reflected to the point *m*, where the image of the star will appear?

T. I do, if there be anything at that point *m* to receive the image.

J. Will not the same rule hold with regard to terrestrial objects?

T. No: for the rays, which proceed from any terrestrial object, however remote, cannot be esteemed strictly parallel; they, therefore, come *diverging*, and will not converge to a *single point*, at the distance of half the radius of the mirror's concavity from the reflecting surface, but in *separate points*, at a little greater distance from the mirror than half the radius.

C. Can you explain this by a figure?

T. I will endeavour to do so. Let A B be a concave mirror, and M E any remote object, from every part of which rays will proceed to every point of the mirror, that is, from the point M rays will flow to every point of the mirror, and so they will

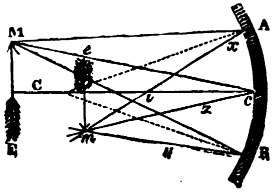


Fig. 17.

from E, and from every point between these extremities. Let us see where the rays that proceed from M to A, c, and B, will be reflected, or, in other words, where the image of the point M will be formed.

J. Will all the rays that proceed from M to different parts of the glass be reflected to a single point?

T. Yes, they will, and the difficulty is to find that point. I will take only three rays, to prevent confusion, viz., M A, M c, M B; and C is the centre of concavity of the glass.

C. Then if I draw C A, that line will be perpendicular to the glass at the point A; the angle M A C is now given, and it is the angle of incidence.

J. And you must make another equal to it, as you did before.

T. Very well. Make C A *x*, equal to M A C, and extend the line A *x* to any length you please.

Now you have an angle M *c* C made with the ray M *c*, and the perpendicular B *c*, which is another angle of incidence.

C. I will make the angle of reflection C *c z* equal to it, and the line *c z* being produced, cuts the line A *x* in a particular point, which I will call *m*.

T. Draw now the perpendicular C B, and you have, with it and the ray M B, the angle of incidence M B C. Make another angle equal to it, as its angle of reflection.

J. There it is, C B *u*, and I find the line B *u* meets the other lines at the point *m*.

T. Then *m* is the point in which all the reflected rays of M will converge; of course, the image of the extremity M of the arrow E M will be formed at *m*. Now the same might be shown of every other part of the object M E, the image of which will be represented by *e m*, which you see is at a greater distance from the glass than half C *c*, or radius.

C. The image is *inverted* also, and *less* than the object; and this, I conclude, will always be the case in similar circumstances.

CONVERSATION XII.

On Concave Mirrors and Experiments on them.

T. If you understand what we conversed on yesterday, and what you have yourselves done, you will easily see how the image is formed by the large concave mirror of the reflecting telescope, when we come to examine the construction of that instrument. In a concave mirror, the image is *less* than the object, when the object is more remote from the mirror than C,

the centre of concavity; and in that case, the image is between the object and mirror.

J. Suppose the object be placed in the *centre* c?

T. Then the image and object will coincide; and if the object is placed nearer to the glass than the centre c, then the image will be more remote and bigger than the object.

C. I should like to see this illustrated by an experiment.

T. Well, here is a large concave mirror. Place yourself before it, beyond the centre of the concavity; and, with a little care in adjusting your position, you will see an inverted image of yourself in the air between you and the mirror, and of a less size than you are. When you see the image, extend your hand gently towards the glass, and the hand of the image will advance to meet it, till they both meet in the centre of the glass's concavity. If you carry your hand still farther, the hand of the image will pass by it, and come between it and the body. Now move your hand to either side, and the image of it will move towards the other.

J. Is there any rule for finding the distance at which the image of an object is formed from the mirror?

T. If you know the radius of the mirror's concavity, and also the distance of the object from the glass.

"Multiply the distance and radius together, and divide the product by double the distance less by the radius, and the quotient is the distance required."

Tell me at what distance the image of an object will be, suppose the radius of the concavity of the mirror be 12 inches, and the object be at 18 inches from it.

J. I multiply 18 by 12, which gives 216; this I divide by double 18, or 36, less by 12, that is 24: but 216 divided by 24 gives 9, which is the number of inches required.

T. You may vary this example, in order to impress the rule on your memory; and I will show you another experiment. I take this bottle partly full of water, and corked, and place it opposite the concave mirror, and beyond the focus, that it may appear to be reversed: now stand a little farther distant than the bottle, and you will see the bottle inverted in the air, and the water, which is in the lower part of the bottle, will appear to be in the upper. I will invert the bottle, and uncork it, and, whilst the water is running out, the image will appear to be filling; but when the bottle is empty, the illusion is at an end.

C. Concave mirrors are, I believe, sometimes used as burning-glasses.

T. Since, as we have seen, it is the property of these mirrors to cause parallel rays to converge to a focus, and since the rays

of the sun are considered as parallel, they are very useful as burning-glasses, and the principal focus is the burning point.

J. Is the image formed by a concave mirror always before it?

T. In all cases, except when the object is nearer to the mirror than the principal focus.

C. Is the image then behind the mirror?

T. It is; and farther behind the mirror than the object is before it. Let A C be a mirror, and *x z* the object between the centre K of the glass and the glass itself; and the image *x y z* will be behind the glass, erect, curved, and magnified, and, of course, the image is farther behind the glass than the object is before it.

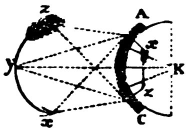


Fig. 18.

J. What would be the effect if, instead of an opaque object *x z*, a luminous one, as a candle, were placed in the focus of a concave mirror?

T. It would strongly illuminate a space of the same dimension as the mirror to a great distance; and if the candle were still nearer the mirror than the focus, its rays would enlighten a larger space. Hence you may understand the construction of many of the lamps which might be seen in many parts of London, before gas was introduced, and which were undoubtedly a great improvement in lighting the streets. Similar principles are often employed in the construction of reflectors for lighthouses.

CONVERSATION XIII.

Of Concave and Convex Mirrors.

T. We shall devote another morning or two to the subject of reflection from mirrors of different kinds.

C. You have not said anything about *convex* mirrors.

T. The images reflected from these are smaller than the objects, erect, and behind the surface; therefore a landscape or a busy scene delineated on one of them, is always a beautiful object to the eye. You may easily conceive how the convex mirror diminishes objects, or the images of objects, by considering in what manner they are magnified by the concave mirror. If *x y z*, in the last diagram, were an object before a *convex* mirror A C, the image by reflection would be *x z*.

J. Would it not appear curved?

T. Certainly: for if the object be a right line, or a plane surface, its image must be curved, because the different points of the object are not equally distant from the reflector. In fact,

the images formed by convex mirrors, if accurately compared with the objects, are never exactly of the same shape.

C. I do not quite comprehend in what manner reflection takes place at a convex mirror.

T. I will endeavour, by a figure, to make it plain: C D represents a convex mirror standing at the end of the room, before which the arrow A B is placed on one side, or obliquely: where must the spectator stand to see the reflected image?

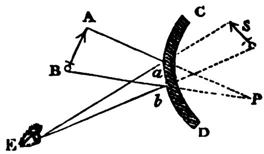


Fig. 19.

C. On the other side of the room.

T. The eye E will represent that situation: the rays from the external parts of the arrow, A and B, flow convergingly along A *a* and B *b*, and if no glass were in the way, they would meet at P; but the glass reflects the ray A *a* along A E, and the ray B *b* along *b* E; and, as we always transfer the image of an object in that direction in which the rays approach the eye, we see the image of A along the line E *a*, behind the glass, and the image of B along E *b*, and, of course, the image of the whole arrow is at S.

By means of a similar diagram, I will show you more clearly the principle of the *concave* mirror. Suppose an object *c* to be beyond the focus F, and the spectator to stand at Z, the rays *c b* and *c d* are reflected, and where they meet in E the spectator will see the image.

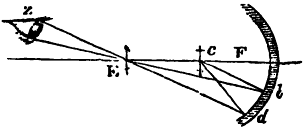


Fig. 20.

J. That is between himself and the object.

T. He must, however, be far enough from it to receive the rays after they have diverged from E, because every enlightened point of an object becomes visible only by means of a cone of diverging rays from it, and we cease to see it if the rays become parallel or converging.

C. Is the image inverted?

T. Certainly; because the rays have crossed before they reach the eye.

You may see this object in another point of view: let *x y* be a concave mirror, and O the centre of concavity: divide O A equally in F, and take the half, the third, and the fourth, &c. of F O, and mark these divisions, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. Let A O be extended, and parts be taken in it equal to F O, at 2, 3, 4, &c. Now if any of the points 1, 2, 3, 4, &c. be the focus of incident rays,

the correspondent point 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. in O F will be the focus of the reflected rays, and *vice versâ*.

J. Do you mean by that, if incident rays be at $\frac{1}{2}$, or $\frac{1}{3}$, or $\frac{1}{4}$, the reflected rays will be at 2, 3, 4?

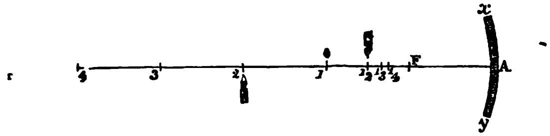


Fig. 21.

T. I do: place a candle at 2, and an inverted image will be seen at $\frac{1}{2}$: now place it at 4, and it will also move back to $\frac{1}{4}$: these images may be taken on paper held in those respective places.

C. I see the farther you proceed one way with the candle, the nearer its inverted image comes to the point F.

T. True; and it never gets beyond it, for that is the focus of parallel rays after reflection, or of rays that come from an infinite distance.

J. Suppose the candle were at O?

T. Then the object and image will coincide: and as the image of an object between F and a concave speculum is on the other side of the speculum, this experiment of the candle and paper cannot be made.

I will now just mention an experiment that we may hereafter make: at one end of an oblong box, about two feet long and fifteen inches wide, is to be placed a concave mirror; near the upper part of the opposite end a hole is made, and about the middle of the box is placed a hollow frame of pasteboard that confines the view of the mirror. The top of the box, next the end in which the hole is made, is covered with a glass, but the other half is darkened. Under the whole are placed, in succession, different pictures, properly painted, which are thrown into perspective by the mirror, and produce a beautiful appearance.

CONVERSATION XIV.

Of Convex Reflection — Of Optical Delusions — Of Anamorphoses.

C. You cannot, I see, make the same experiment with the candle and a convex mirror, that you made yesterday with the concave one.

T. Certainly not, because the image is formed behind the glass; but it may, perhaps, be worth our while to consider how the effect is produced in a mirror of this kind. Let *a b* repre-

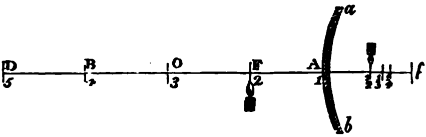


Fig. 22.

sent a convex mirror, and A *f* be half the radius of convexity, and take A F, F O, O B, &c. each equal A *f*. If incident rays flow from 2, the reflected rays will appear to come from behind the glass at $\frac{1}{2}$.

J. Do you mean, if a candle be placed at 2, the image of it will appear to be formed at $\frac{1}{2}$ behind the glass?

T. I do: and if that or any other object be carried to 3, 4, &c., the image will also go backward to $\frac{1}{3}$, $\frac{1}{4}$, &c.

C. Then, as a person walks towards a convex spherical reflector, the image appears to walk towards him, constantly increasing in magnitude, till they touch each other at the surface.

T. You will observe that the image, however distant the object, is never farther off than at *f*; that is, the imaginary focus of parallel rays.

J. The difference then between concave and convex reflections is, that the point *f* in the *former* is behind the glass, and in the *latter* it is before the glass, as F.

T. Just so: from the property of diminishing objects, "small convex reflectors," says Dr. Gregory, "are made for the use of travellers, who, when fatigued by stretching the eye to Alps towering on Alps, can, by their mirror, bring the sublime objects into a narrow compass, and gratify the sight by pictures which the art of man in vain attempts to imitate."*

Concave mirrors have been used for many other and different purposes; for, by them, with a little ingenuity, a thousand illusions may be practised on the ignorant and credulous.

C. I remember going with you to see an exhibition in Bond Street, which you said depended on a concave mirror: I was desired to look into a glass; I did so, and started back, for I thought the point of a dagger would have been in my face. I looked again, and a death's head snapped at me: and then I

* See Economy of Nature, vol. i. p. 26., second edition.

saw a most beautiful nosegay, which I wished to grasp, but it vanished in an instant.

T. I will explain how these deceptions are managed: let E F be a concave mirror 10 or 12 inches in diameter, placed in one

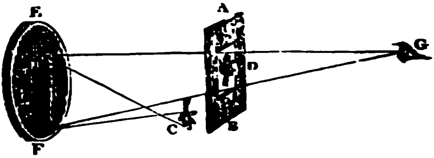


Fig. 23.

room; A B the wainscot that separates the spectator from it; but in this there is a square or circular opening which faces the mirror exactly. A nosegay, for instance, is inverted at C, and is strongly illuminated by means of an Argand lamp; but no direct light from the lamp falls on the mirror. Now a person standing at G will see an image of the nosegay at D.

J. What made it vanish?

T. A person behind the wainscot removed the nosegay, and ntroduced the sword and the advancing death's head. Persons have undertaken to exhibit the ghosts of the dead by contrivances of this kind; for if a drawing of the deceased be placed instead of the nosegay, it may be done.

If a large concave mirror be placed before a blazing fire, so as to reflect the image of the fire on the flap of a bright mahogany table, a spectator suddenly introduced into the room will suppose the fire to be on the table.

If two large concave mirrors, A and B, be placed opposite each other, at the distance of several feet, and red-hot charcoal, or an iron ball, be put in the focus D, and some gunpowder in the other focus C, it will presently take fire. This experiment may be varied by placing a thermometer in one focus and lighted charcoal in the other, and it will be seen that the quicksilver in the thermometer will rise as the fire increases, though another thermometer, at the same distance from the fire, but not in the focus of the glass, will not be affected by it.

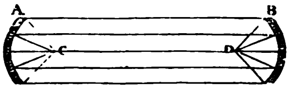


Fig. 24.

At the Polytechnic Institution are two very large reflectors of this kind: they are placed at the opposite ends of the long gallery, 80 or 100 feet apart; a fire is placed in the focus of one, and a chop or steak in the focus of the other, and the meat

is cooked. But I must not go on telling you about the reflection of heat, for light is our present subject.

J. I have seen concave glasses, in which my face has been rendered as long as my arm, or as broad as my body: how are these made?

T. These images are called *anamorphoses*, and are produced from *cylindrical* concave mirrors; and as the mirror is placed either *upright* or on its *side*, the image of the picture is distorted into a very long or very broad image.

In the cloister of Minims, at Paris, there are two anamorphoses traced upon two of the sides of the cloister, one representing a Magdalen, and the other St. John writing his Gospel. These, when viewed directly, seem like a kind of landscape, but, from a particular point of sight, they appear very distinctly like human figures.

Reflecting surfaces may be made of various shapes, and if a regular figure be placed before an irregular reflector, the image will be deformed; but if an object, as a picture, be painted deformed, according to certain rules, the image will appear regular. Such figures and reflectors are sold by opticians, and they serve to astonish those who are ignorant of these subjects; but you will readily comprehend their nature from what has just been remarked.

CONVERSATION XV.

Of the different Parts of the Eye.

C. Will you now describe the nature and construction of the telescope?

T. I think it will be better first to explain the several parts of the eye, and the nature of vision in the simple state, before we treat of those instruments which are designed to assist it.

J. I once saw a bullock's eye dissected, and was told that it was analogous to the human eye in its several parts.

T. The eye, when taken from the socket, is of a globular form, and it is composed of three coats or skins, and three other substances called humours. The first figure represents the section of an eye, that is, an eye cut down the middle; and the second the front view of an eye as it appears in the head. The external coat, which is represented by the outer circle A B C D E, is called the *sclerotica;* the front part of this, namely, C *x* D, is perfectly transparent, and is called the *cornea;* beyond this, towards B and E, it is white, and called the white of the

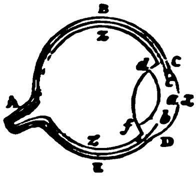


Fig. 25.

Fig. 26.

eye. The next coat, which is represented by the second circle, is called the *choroides*.

J. This circle does not go all round.

T. No: the vacant space *a b* is that which we call the pupil, and through this alone the light is allowed to enter the eye.

C. What do you call that part which is of a beautiful blue in some persons, and in others brown or almost black?

T. That, as *a c*, *b a*, is part of the *choroides*, and is called the *iris*.

C. The iris is sometimes much larger than it is at another.

T. It is composed of a sort of network, which contracts or expands, according to the force of the light in which it is placed. Let James stand in a dark corner for two or three minutes now look at his eyes.

C. The *iris* of each is very small, and the pupil large.

T. Now let him look steadily, rather close to the candle.

C. The iris is considerably enlarged, and the pupil of the eye is but a small point in comparison of what it was before.

T. Did you never feel uneasy, after sitting some time in the dark, when candles were suddenly brought into the room?

J. Yes: I remember, last Friday evening, we had been sitting half an hour almost in the dark, at Mr. Webb's, and, when candles were introduced, every one of the company complained of the pain which the sudden light occasioned.

T. By sitting so long in the dark, the iris was contracted very much: of course, the pupil being very large, more light was admitted than it could well bear; and, therefore, till time was allowed for the iris to adjust itself, the uneasiness would be felt.

C. What do you call the third coat, which, from the figure, appears to be still less than the choroides?

T. It is called the *retina*, or network, which serves to receive the images of objects produced by the refraction of the different humours of the eye, and painted, as it were, on the surface.

C. Are the humours of the eye intended for refracting the rays of light, in the same manner as glass lenses?

T. They are; and they are called the *vitreous*, the *crystalline*, and the *aqueous* humours. The *vitreous* humour fills up all the space *z z*, at the back of the eye; it is nearly of the substance of melted glass. The *crystalline* is represented by *d f*, in the shape of a double convex lens, and the *aqueous*, or watery humour fills up all that part of the eye between the crystalline humour and the cornea C *x* D.

J. What does the part A at the back of the eye represent?

T. It is the optic nerve, which serves to convey to the brain the sensations produced on the retina.

C. Does the retina extend to the brain?

T. It does: and we shall, when we meet next, endeavour to explain the office of these humours in effecting vision. In the mean time I would request you to consider again what I have told you of the different parts of the eye; and examine, at the same time, the last two figures.

J. We will: but you have said nothing about the uses of the eyebrows and eyelashes.

T. I intended to have reserved this to another opportunity; but I may now say, that the eyebrows defend the eye from too strong a light; and they preserve the eyes from injuries by the sliding of substances down the forehead into them.

The eyelids act like curtains to cover the eyes during sleep; to protect them from accidental violence; to exclude the light when most offensive; and, when we are awake, they diffuse a fluid over the eye, which keeps it clean, and well adapted for transmitting the rays of light.

The eyelashes, in a thousand instances, guard the eye from danger, and protect it from floating dust, with which the atmosphere abounds. So mercifully does the Author of Nature provide against injury to this delicate organ, even by means of its ornamental appendages.

CONVERSATION XVI.

Of the Eye and the Manner of Vision.

C. I do not understand what you meant, when you said the optic nerve served to convey to the brain the sensations produced on the retina.

T. Nor do I pretend to tell you in what manner the image of any object painted on the retina of the eye is calculated to convey to the mind an idea of that object: but I wish to show

you, that the images of the various objects which you see are painted on the retina. Here is a bullock's eye, from the back part of which I cut away the three coats, but so as to leave the vitreous humour perfect: I will now put against the vitreous humour a piece of white paper, and hold the eye towards the window: what do you see?

J. The figure of the window is drawn upon the paper; but it is inverted.

T. Open the window, and you will see the trees in the garden drawn upon it in the same inverted state, or any other bright object that is presented to it.

C. Does the paper in this instance represent the innermost coat called the retina?

T. It does; and I have made use of paper, because it is easily seen through, whereas the retina is opaque: transparency would be of no advantage to it. The retina, by means of the optic nerve, is extended to the brain, or, in other words, the retina is an extension of the optic nerve.

J. And does it, as one may say, carry to the brain the news of every object that is painted on the retina?

T. So it should seem; for we have an idea of whatever is drawn upon it. I direct my eyes to you, and the image of your person is painted on the retina of my eye, and I say I see you. So of anything else.

C. You said the rays of light proceeding from external objects were refracted in passing through the different humours of the eye.

T. They are, and converged to a point, or there would be no distinct picture drawn on the retina, and, of course, no distinct idea conveyed to the mind. I will show what I mean by a figure, taking an arrow again as an illustration.

As every point of an object A B C sends out rays in all directions, some rays, from each point on the side next the eye, will fall upon the cornea between *x* and *y*, and, by passing through the humours of the eye, they will be converged, and brought to as many points on the retina, and will form on it a distinct inverted picture, *c b a*, of the object.

J. This is done in the same manner as you showed us by means of a double convex lens.

T. All three of the humours have some effect in refracting the rays of light, but the crystalline is the most powerful; and that is a complete double convex lens: and you see the rays from A are brought to a point at *a*; those at B will be converged at *b*, and those from C at *c*; and, of course, the intermediate ones between A and B, B and C, will be formed between *a* and *b*,

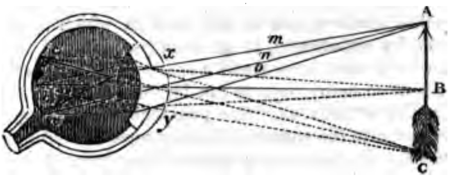


Fig. 27.

and *b* and *c*. Hence the object becomes visible by means of the image of it being drawn on the retina.

C. Since the image is inverted on the retina, how is it that we see things in the proper position?

T. This is a proper question, but one that is not very readily answered. It is well known that the sense of touch or feeling very much assists the sense of sight; some paintings are so exquisitely finished, and so much resemble sculpture, that the eye is greatly deceived; we then naturally extend the hand to aid the sense of seeing. Children, who have to learn the use of all their senses, make use of their hands in everything; they see nothing which they do not wish to handle; and therefore it is not improbable that, by the sense of the touch, they learn, unawares, to rectify that of seeing. The image of a chair, or table, or other object, is painted in an inverted position on the retina; they feel and handle it, and find it erect; the same result perpetually recurs, so that, at length, long before they can reason on the subject, or even describe their feeling by speech, the inverted image gives them an idea of an erect object.

C. I can easily conceive that this would be the case with common objects, such as are seen every day and hour. But will there be no difficulty in supposing that the same must happen with regard to anything which I had never seen before? I never saw ships sailing on the sea till within this month; but when I first saw them, they did not appear to me in an inverted position.

T. But you have seen water and land before, and they appear to you, by habit and experience, to be lowermost, though they are painted on the eye in a different position: and the bottom of the ship is next the water, and, consequently, as you refer the water to the bottom, so you must the hull of the ship, which is connected with it. In the same manner all the parts of a distant prospect have a natural arrangement with respect to each other; and, therefore, though there may be a hundred objects

in the landscape entirely new to you, yet, as they all bear a relation to one another, and to the earth in which they are, you refer them, by experience, to an erect position.

J. How is it that, in so small a space as the retina of the eye, the images of so many objects can be formed?

T. Dr. Paley* tells us, "the prospect from Hampstead Hill is compressed into the compass of a sixpence, yet circumstantially represented. A stage-coach approaching you, at its ordinary rate, for half an hour, passes in the eye only over the twelfth part of an inch, yet the change of place is distinctly perceived throughout its whole progress." Now what he asserts we all know is true: go to the window, and look steadily at the prospect before you, and see how many objects you can discern without moving your eye.

J. I can see a great number very distinctly indeed; besides which I can discern others, on both sides, which are not clearly defined.

C. I have another difficulty; we have two eyes, on both of which the images of objects are painted; how is it that we do not see every object double?

T. A common reply to this question would have been to say that the optic nerves are so framed, that the correspondent parts in both eyes lead to the same place in the brain, and excite but one sensation; but there are certain phenomena in the physiology of vision that have been long overlooked, although obvious to all, which are opposed to so hasty a decision — a decision which, after all, is not in conformity with the fact. The subject of binocular vision is so important, that we must devote an entire conversation to it, and, in the mean time, I will prepare the means of illustration; and I think you will then agree with me in wondering that facts of such every-day occurrence as some that I shall show you are, should not have arrested the minds of philosophers until Wheatstone investigated the subject in 1838.

CONVERSATION XVII.

Binocular Vision.—The Stereoscope.—The Pseudoscope.

T. I wish to prove to you that the pictures formed on the respective retinæ of our two eyes are not always similar; and that what we see is not one of these pictures, nor the other, but an effect of both. I have here a small disc of brass, with one of

* See Paley's Natural Theology, p. 35., seventh edition; or p. 13. in the Analysis of that work *by the Author of these Dialogues.*

the faces turned in the lathe, and thus presenting a bright surface of concentric circles. Take this in your hand, and stand facing the candle, holding the disc between you and the candle, in such a manner as to reflect the light to your eye. Now, what do you see?

C. Dear me! it looks exactly as if an arrow of light were thrust through the centre of the disc; and one half seems to descend under the surface of the disc, while the other half rises as much above. I can hardly persuade myself that the disc is not actually pierced by the ray.

T. Now close the right eye, and tell me what you see; then close the left in like manner.

C. I now see that the ray of light, instead of piercing the disc, lies flat across it in each case.

T. If you look more closely, you will see that the ray seen by the right eye lies across in a different direction to that seen by the left. In fig. 28. *a* will represent the direction of the ray seen by the right eye, and *b* that seen by the left.

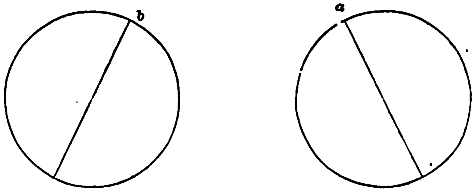


Fig. 28.

When both eyes are open, the impression produced on the brain by these two different reflections is that of a ray piercing the surface.

J. In this case, seeing is not believing, and two eyes are not to be relied on so much as one.

T. Not so fast. We will look at something else, and you will find the value of having a pair of eyes. Take this cube, one face of which I have painted black, and place it directly before you six or eight inches from the eyes, and with the black face to your right hand. Now cover your right eye, and move your head till you just lose sight of the black face. Having done this, cover the left eye and open the right, not moving your head.

J. I can now see the black face again; and I observe that the perspective view of the cube is different according as I view it with one or other eye.

T. It is; in either case, you see a simple perspective view of

the object; and it is the combination of these two perspectives which represents to the brain the solid object.

C. Then the Cyclops, with his one eye, could not tell whether an object was solid or not?

T. Not by a single observation, but he would move his head, and make two observations; and, if the perspectives did not agree, he would then know it was a solid.

C. Then this is why the solids in our geometry books never look really solid; they seem make-believes. They are drawn in perspective, but there is not a different perspective for each eye; there is but one for both eyes.

T. True; for to use Wheatstone's words, "It is impossible for an artist to give a faithful representation of any near solid object, that is, to produce a painting which shall not be distinguished in the mind from the object itself."

J. I have been looking at the house on the distant hill, first with one eye and then with the other, and see no difference in the perspective; and yet I know it *is* a solid body.

T. But this *sight* of it has not taught you of its solidity. As far as you know from what you *see*, it may be merely a painting on a flat surface; but from your own previous knowledge of the nature of houses, and from having visited with me that particular house, you know what you see.

I will now show you Wheatstone's Stereoscope; and you will be prepared to understand the principles on which it is constructed. There are two forms, the refracting and the reflecting; the former suited for small subjects alone; the latter applicable to large subjects. We will begin with the former. It consists (fig. 29.) of a base, *a*, 6 in. by 4 in., on which stands an upright partition, *b*, 5 in. high, and which can be extended by means of a slide, *c*. It supports a board, *d*, corresponding with the base, having two apertures, *e* and *f*, one on each side, and 2½ in. apart, to correspond with the distance of the eyes; small prisms are in these apertures; or lenses. When the instrument is constructed without the partition, the upper part is otherwise supported. Sometimes, the whole is enclosed in, and a flap is raised at one side to admit the light. Very marvellous effects are produced by this simple instrument, to some of which I will refer. Fig. 30. represents

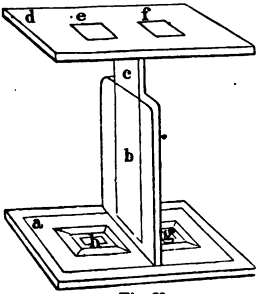


Fig. 29.

perspective drawings of the cube, as it appears to each eye; *a* being the appearance presented to the right eye, and *b* that

Fig. 30.

presented to the left. If these are duly placed in the stereoscope (fig. 29.), *a* at *g*, and *b* at *h*, so that the right eye regards its own perspective view, and the left its own, the effect produced will be as if the real cube were before the eyes. If two circles, with diagonals similar to those in fig. 28., are placed in the instrument, the result will be a disc pierced by a line, in the same manner as we had imagined the brass disc to have been pierced by a ray of light.

C. The effect is indeed surprising: and does the same rule apply to all other cases?

T. It does: all that is necessary is to make correct drawings of the respective perspective views of the objects, and the effect will come out most successfully. I have here a large collection, which are to be obtained at small cost ready prepared; some being of the more simple solids, which at once tell of the form that will be more perfectly revealed by the stereoscope; others of a more complex character. Forms to which we are not so much accustomed are not easily made out of themselves, but when placed in the stereoscope become solid realities.

But the most striking of all objects thus viewed, are daguerreotype pictures. I have here some pairs of perspectives of statues and portraits.

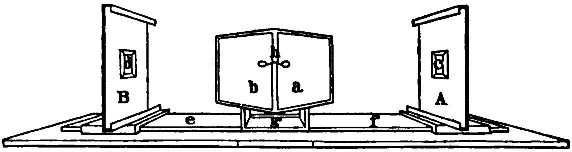
J. These are indeed excellent: in this of the Greek Slave, which was so much admired as a statue at the Great Exhibition, the limbs seem actually rounded; and have, from two somewhat obscure looking perspectives, the appearance of a solid statue.

C. Why these are model portraits of papa and mamma. I can actually see into the hat, and round the arm, and through the hair; and the bonnet ribbon seems lifted up, and the curls are quite solid, and the handkerchief is perfectly transparent, so that the dress is visible beneath. Papa's fingers, the folds of his coat and waistcoat, the tie of his cravat, are all like those of a living statue; and I can actually see into the folds of lace on mamma's wrists.

T. Pictures of this kind are necessarily the very best objects for this interesting instrument; for there can be no errors in their perspective. I may one day describe * to you the principles of the process by which they are produced. For the present you have merely to understand that a silver plate, properly prepared, is placed in a camera, which is presented to the person or object to be copied; and a change speedily occurs on the plate, which by subsequent treatment reveals a portrait. When one picture is taken the camera is shifted, and then another is taken. For a stereoscope, having a focal distance of eight inches, the camera is moved 18°, or the twentieth part of the circumference of the circle, of which a line drawn from the object to the camera is the diameter.

C. And what is the reflecting stereoscope?

T. In principle the same, but in construction different: it is shown in fig. 31. Its essential parts are two vertical and



[Fig. 31.]

parallel boards or frames, A and B, to hold the pictures, *c*, *d*; and two plane mirrors *a* and *b*, placed at right angles to each other to reflect the pictures to the eye. The rest of the apparatus consists merely of the framework and adjustments. The eyes are applied, one to each mirror; and it is generally better to attach a spectacle frame, *h*, with a pair of moderately magnifying lenses, facing the eyes. All the phenomena before mentioned are equally seen here: but the former arrangement is only suited to small objects, whereas here, from the nature of the arrangements, we are not limited to size; and hence, I can show you some magnificent pictures.

C. How beautiful! I see a perfect model of the transept of the Great Exhibition. The famous old elm stands out in full relief; the statues and ornaments, the gates and fountains, are all so naturally placed in real perspective, that were I to have seen this before having had the secret explained, I should have thought I was looking on a small and most perfectly executed model.

* See Conversation XXIV., on the Chemical Properties of Light.

T. The pictures in the present instance are on paper. They are sun-pictures, taken by a process essentially similar to the daguerreotype. The reflecting stereoscope, on account of its properties, and the extent of its capabilities, is becoming an instrument extremely useful to the architect and the engineer. Instead of the expense and the care of making drawings illustrative of the progress of the works, it is now merely necessary to take sun-pictures in the camera, under the necessary angles, and place them in the stereoscope, when the reality of the building in its then state is presented to the eye. This plan is being adopted by Mr. Vignoles, the celebrated engineer, in respect to the wrought-iron bar chain suspension bridge, in course of construction at Kieff over the river Dnieper, by command of the Emperor of Russia. You remember seeing the model of this bridge in the central avenue of the Great Exhibition: it is engraved at p. 314. of the Illustrated Catalogue. The Emperor of Russia is provided with a reflecting stereoscope: the engineer is provided with two first-class cameras, and an experienced manipulator. Week by week he takes sun-pictures of the state of the works, and sends them, in a proper state, and with a brief description, to the Emperor. His Imperial Majesty places them in the camera, and with his own eyes sees the actual state of things, and has before him an irresistible reply to all that his courtiers may insinuate against the English engineer.

C. Capital! how many uses can be made of this simple instrument! I am quite sure the eleventh book of Euclid would have been much more easy to me, had I had stereoscopic views of the figures. They plagued me very much.

T. There are some curious deceptions presented by some forms of regular solids; and they command our attention now, as we are upon the subject of vision. Look attentively at the figure 30. *a*, and you will observe it change; you will at times observe the corner *x* to be the nearest to you, and the figure at that time will be like as if you could see the lower surface of the base; if you continue to look, the figure will on a sudden appear to turn inside out, the corner *x* will seem to belong to the distant side, and be one corner of the square base, on which the figure will then seem to rest; and what is the more remarkable, these changes cannot be called forth at pleasure, but will come and go, independently of any wish of yours to the contrary. This delusion only occurs with regular forms, of which both arrangements are familiar, and can be realised by the mind; and only in linear figures, as the mere presence of shade at once identifies which of the two forms is intended, and dispels the illusion.

J. While I have been listening to you, I inadvertently placed the forms, *a* and *b*, fig. 30., in the wrong places in the stereoscope, and was not aware of it, until I looked through at them in the expectation of finding as before a solid cube, when to my surprise I saw a pyramid, with a small piece cut off the top.

T. This is as it should be. For a frustrum of a pyramid viewed with either eye would give you for each eye perspectives such as you have; viz. for the left eye a figure similar to that of a cube seen with the right eye, and for the right eye, one similar to a cube seen with the left eye; and the cause of this alternation is that the parts, which at first seemed near, now seem remote, and the remote seem near.

C. I can quite understand what you just now said about the effect of shade. I have a machine-engraving of a medallion of one of the popes: when I look at it with the lamp on the right side, it seems to be a medallion; but when I place the lamp on the left, it appears to be intaglio, or sunk in. Nothing alters, as far as the picture is concerned; but as a medallion, its light and shade correspond with what is true, when the light is on the right hand; but with the light on the left, they could only be true for an intaglio. And this makes me think that the *eye* and the *mind* are both concerned in the act of seeing.

T. They are, as you will have half discovered from some of the other experiments.

C. I think I shall make myself a stereoscope of card and wood, with two holes to look through. I shall not want any prisms or lenses, for my eyesight is very good.

T. You may perhaps succeed, and perhaps not. Some eyes will much more readily adjust themselves to circumstances than others, and some will not at all. I can see without lenses, but not at first. When I begin to look, I see the two pictures; but after a little attentive looking, they gradually superpose and coalesce, and the solid is revealed. The sole use of the lenses is to render the rays of light parallel, which it is necessary they should be, for distinct vision, when the optic axes are parallel, as in this case they are, the centres of the pictures being about as far apart as are the two eyes. *Prisms* deflect the rays of light that proceed from the pictures, so as to make them appear to occupy the same place. *Semi-lenses*, with their edges directed towards each other, as have been used by Sir David Brewster, serve both to displace the pictures, and also to render the rays less convergent. Lenses and prisms united, enable us to see pictures that are somewhat wider from centre to centre than the width between the eyes.

If the frames which hold the pictures in the reflecting stereo-

scope (fig. 31.) are on arms *e f*, movable about a centre *g*, we can see how much the direction of the lines is connected with binocular vision. If the arms are moved back, although the *distance* of the pictures from the mirrors remains the same, the size becomes greater to the eyes; if they are moved forwards, the size becomes smaller. In either case, the *position* of the picture reflected in the mirror is altered, so that in the former case, the lines converge less than for the true view; and in the latter case they converge more.

C. But I cannot see how this is to magnify or to diminish the picture. If I stand at one end of the study, and look at my cricket-ball on the table at the other end, two lines drawn from my eyes to the ball are nearly parallel; if I go to the middle of the room, the lines converge or slope towards each other, but the ball seems no bigger; it is nearer.

T. Just so; but in the stereoscope, when you move back the arms, the lines from your eyes converge; but the pictures do not get nearer, and thus you have the effect of increased size, without the information to help you, as in the case of the ball, that although it seems larger, it is not so, but is nearer.

I could tell you of many curious effects connected with the relative convergence of the optic axes, but must content myself with describing to you an instrument which Mr. Wheatstone has invented, and which he has termed a *Pseudoscope*, on account of the false perceptions it conveys to the mind. You have seen, in regard to your ball, that the impression on your mind of its real magnitude is the same, whether it be far or near, for the size of the picture drawn on the retina of the eye (fig. 27.) is larger as the axes converge more, and there is a constant relation between the two. The pseudoscope is so constructed that as an object becomes nearer, its larger picture on the retina is accompanied by a *less* convergence of the optic axes, instead of a *greater*; or, when regarding two objects, at no great distance from the eye, but the one nearer than the other, the nearer will appear the more distant. I will first describe to you the pseudoscope; and then, after having shown you some of its effects, will endeavour to explain its *modus operandi*.

Fig. 32. represents the pseudoscope. It consists essentially of a pair of rectangular prisms *a* and *b*, fitted into frames *c d*, so that the parallel sides *e* and *f*, are about $2\frac{1}{10}$ in. apart; the other faces are about $1\frac{2}{10}$ in. square. The frames in which the respective prisms are held are slightly adjustible on centres at *x*, so as to bring the objects to coincide. On looking through this, as shown in the figure at *g g*, the inside of a tea-cup appears as a solid convex body; coloured flowers in relief on a china vase

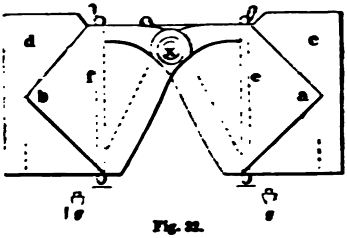


Fig. 22.

appear as if impressed in; a small terrestrial globe appears like a glass globe, with a hemisphere drawn on its further and concave surface; and if then the globe is revolved, fresh portions of the surface seem to come from nowhere, and to go to nowhere.

C. I cannot see anything different in the tea-cup. Oh! there it is; it seemed on a sudden to turn inside out, and jump towards me.

T. This is generally the case. The real impression on the mind is so strong, that it will not readily give place to the impressions actually on the retinæ; and with some, the relation between the susceptibility of the retinæ and the tenacity of the mind is such that the effect cannot be at all caught.

These conversions of relief only occur with objects whose reverses have a meaning; and they do not occur at all if the object presents light and shade, because then one set of signs neutralises and sets aside the other. In order that more remote objects shall appear nearer, they must be viewed isolated from all extraneous things, or these will reveal more strongly the true state of the case, than the pseudoscope will the converse. An object on a wall appears behind it. The branches of a plant that are farthest from the eye seem nearest, and the whole plant seems broken up and cut in a most extraordinary way, but in strict accordance with rule.

C. You have placed the plant on the table, behind the lamp; but its branches, especially the top ones, seem nearer to me than the lamp; and the more so, as I avoid looking at the foot; in the latter case, the true state of things is revealed by the table-cover, and other things.

T. Yes; and if you notice as I move the plant nearer, it will present two contradictory effects; it will seem to go further off, and yet to become larger; for, as the object becomes nearer, its larger picture on the retina is by this instrument made to be accompanied by a *less* and not a *greater* convergence of the optical axis, or lines from each eye. For the lines

drawn from the object on entering the prism suffer refraction, or are bent inwards; they are then reflected by the inner face of the prism and pass on to the eye, and on leaving the prism are bent outwards. The final result of these refractions and reflections is that the lines which converge most, on entering the prism, converge least on leaving it, and *vice versâ*.

The diagram (fig. 33.) will help you to remember what is meant by convergence of the optic axis, and by the greater or less angles under which nearer or more distant objects are viewed. Let R and L be the right and left eyes, and A and B two objects, the one near, the other more remote. The lines drawn from the two eyes converge and make a larger angle at the nearer object A; and converge and make a much smaller angle at the more distant object B. You may consider that the action of the pseudoscope is as if the line R B is made to assume the direction R A before entering the eye; and the line R A to assume the direction R B.

You may from the same diagram see the value of two eyes in order to give an idea of *solidity* and of *distance*. If A were a small solid, one eye L could only see one end of it; but the other eye R could see a side, as well as a portion of one end, as shown by the dotted line; and this twofold evidence proves the solidity. In regard to distance, if A and B were both some distance off, it would not be easy with one eye L to discover which were the more distant; but, as soon as the evidence of the other eye R is obtained, B is at once proved to be the more distant.

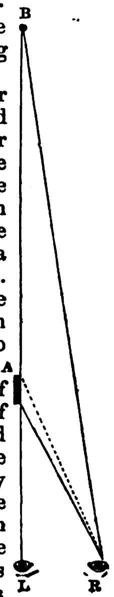


Fig. 33.

CONVERSATION XVIII.

Of Spectacles, and of their Uses.

C. Why do people wear spectacles?

T. To assist the sight, which may be defective from various causes. Some eyes are too flat, others are too convex: in some the humours lose part of their transparency, and on that account much light that enters the eye is intercepted and lost in the passage, and every object appears dim. Without light, the eye would be a useless machine. Spectacles are intended to collect the light, or to bring it to a proper degree of convergency.

C. Are spectacle-glasses always convex?

T. No: they are convex when the eyes are too flat; but, if the eyes are already very convex, then concave glasses are used. You know the properties of a convex glass?

J. Yes; it is to make the rays of light converge sooner than they would without.

T. Suppose, then, a person is unable to see objects distinctly, owing to the cornea C D, or to the crystalline humour *b*, or both,

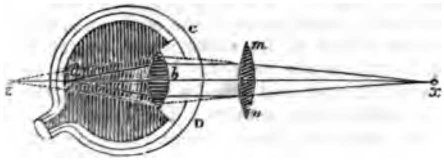


Fig. 34.

being too flat. The focus of rays proceeding from any object, *x*, will not be on the retina, where it ought to be, but at *z* beyond it.

C. How can it be beyond the eye?

T. It would be beyond it, if there were anything to receive it; as it is, the rays flowing from *x* will not unite at *d*, so as to render vision distinct. To remedy this, a convex glass *m n* is placed between the object and the eye, by means of which the rays are brought to a focus sooner, and the image is formed at *d*.

J. Now I see the reason why people are obliged, sometimes, to make trial of many pairs of spectacles before they get those that will suit them. They cannot tell exactly what degree of convexity is necessary to bring the focus just to the retina.

T. That is right; for the shape of the eye may vary as much as that of their countenance; of course, a pair of spectacles that might suit you, would not be adapted to another, whose eyes should require a similar aid.—What is the property of concave glasses?

C. They cause the rays of light to diverge.

T. Then for very round and globular eyes these will be useful, because, if the cornea C D, or crystalline humour, *b*, be too convex, the rays flowing from *x* will unite into a focus before they arrive at the retina, as at *z*.

C. If the sight then depend on sensations produced on the retina, such a person will not see the object at all, because the image of it does not reach the retina.

T. True: but at *z* the rays cross one another, and pass on to the retina, where they will produce some sensations, but not those of distinct vision, because they are not brought to a focus

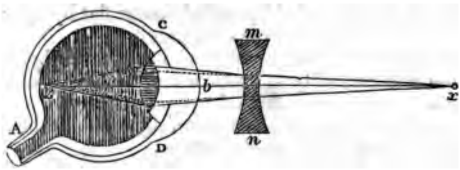


Fig. 35.

there. To remedy this, the concave glass *m n* is interposed between the object and the eye, which causes the rays coming to the eye to *diverge;* and, being more divergent when they enter the eye, it requires a very convex cornea or crystalline to bring them to a focus at the retina.

J. I have seen old people, when examining an object, hold it a good distance from their eyes.

T. Because, their eyes being too flat, the focus is thrown beyond the eye, and therefore they hold the object at a distance to bring the focus *z*, in the last figure but one, to the retina.

C. Very short-sighted people bring objects close to their eyes.

T. Yes; I once knew a young man who was apt, in looking at his paper, to rub out with his nose what he had written with his pen. In this case, bringing the object near the eye produces a similar effect to that produced by concave glasses: because, the nearer the object is brought to the eye, the greater is the angle under which it is seen; that is, the extreme rays, and, of course, all the others, are made more divergent.

J. I do not understand this.

T. Do you not? Look, then, to this diagram, in which let E be the eye, and the object *a b* seen at *z*, and also at *x*, double

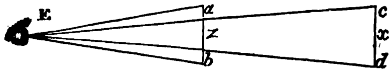


Fig. 36.

the distance; will not the same object appear under different angles to an eye so situated?

J. Yes, certainly; *a* E *b* will be larger than *c* E *d*, and will include it.

T. Then the object being brought very near the eye has the same effect as magnifying the object, or of causing the rays to diverge; that is, though *a b* and *c d* are of the same lengths, yet *a b*, being nearest to the eye, will appear the largest.

C. You say the eyes of old people become flat by age; is that according to the natural course of things?

T. It is; and therefore persons who are very short-sighted while young will probably see well when they grow old.

J. That is an advantage denied to common eyes.

T. But people, blessed with common sight, should be thankful for the benefit they derive while young.

J. And I am sure we cannot too highly estimate the science of optics, that affords such assistance to defective eyes, which, in many circumstances of life, would be useless without them.

T. Spectacles were known and used long before the principle of the microscope and telescope was brought into action. Salvinus Armatus, a nobleman of Florence, claimed the honour of the invention of spectacles: he died in 1317, and the fact was inscribed on his tomb. But it is generally believed that Alhazen was the real inventor, 50 or 60 years prior to this period.

CONVERSATION XIX.

Of the Rainbow.

T. You have frequently seen a rainbow?

C. Oh, yes; and very often I have seen two at the same time, one above the other; the lower being by far the more brilliant.

T. This is one of the most beautiful phenomena in nature; it never makes its appearance but when a spectator is situated between the sun and the shower; and it depends on the reflection and refraction of the rays of the sun by the falling drops. You know the beauty of the rainbow consists in its colours. I will show you the colours first by means of the

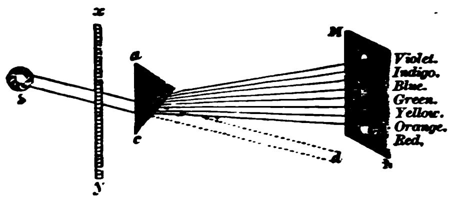


Fig. 87.

prism. If a ray of light s be admitted into a darkened room, through a small hole in the shutter *x y*, its natural course is along to the line *d*; but if a glass prism *a c* be interposed, the whole ray will be bent upwards; and, if it be received on any

white surface, as M N, it will form an oblong image P T, the breadth of which is equal to the diameter of the hole in the shutter.

J. But how is the light, which is admitted by a *circular* hole in the window, spread out into an oblong?

T. If the ray were of one substance, it would be equally bent upwards, and make only a small circular image. Since, therefore, the image or picture is oblong, it is inferred, that it is formed of rays differently refrangible, some of which are turned more out of the way, or more upwards than others: those which go to the upper part of the spectrum being most refrangible, those which go to the lowest part are the least refrangible; the intermediate ones possess more or less refrangibility, according as they are painted on the spectrum. Do you see the seven colours?

C. Yes; here is the *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*.

T. These colours will be still more beautiful, if a convex lens be interposed, at a proper distance, between the shutter and the prism: you may easily recollect both the names of the colours and their order, by forming with their initials the mnemonic word *vibgyor*.

J. How does this apply to the rainbow?

T. Suppose A to be a drop of rain, and S *d* a ray from the sun, falling upon or entering it at *d*, it will not go to *c*, but be refracted to *n*, where a part will go out, but a part also will be reflected to *q*, where it will go out of the drop, which, acting like a prism, separates the ray into its primitive colours; the violet will be uppermost, the red lowermost.

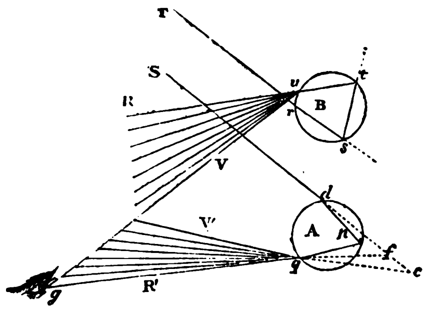


Fig. 38.

In the above cut R and R' represent *red* rays; and V and V' *violet* rays.

C. Is this always the case, be the sun either high or low in the heavens?

T. It is; but the situation of the rainbow will vary, according as the sun is high or low; that is, the higher the sun, the lower will be the rainbow: a shower has been seen on a mountain by a spectator in a valley, by which a complete circular rainbow has been exhibited.

J. And I once remember standing on Morant's Court Hill, in Kent, when there was a heavy shower, while the sun shone very bright, and all the landscape beneath, to a vast extent, seemed to be painted with the prismatic colours.

C. You have not explained the principles of the upper or fainter bow.

T. This is formed by two refractions and two reflections; suppose the ray T *r* to be entering the drop B at *r*. It is refracted at *r*, reflected at *s*, reflected again at *t*, and refracted as it goes out at *u*, whence it proceeds, being separated, to the spectator at *g*. Here the colours are reversed; the angle formed by the red ray is less than that formed by the violet.

J. Does the same thing happen with regard to a whole shower, as you have shown with respect to the two drops?

T. Certainly; and by the constant falling of the rain, the image is preserved constant and perfect. Here is the representation of the two bows. The rays come in the direction S A, and the spectator stands at E, with his back to the sun, or, in other words, he must be between the sun and the shower.

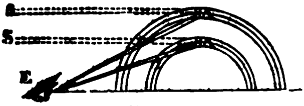


Fig. 39.

This subject may be shown in another way; if a glass globule filled with water be hung sufficiently high before you, when the sun is behind, to appear red, let it descend gradually, and you will see in the descent all the other six colours follow one another. Artificial rainbows may be made with a common watering pot, but much better with a syringe fixed to an artificial fountain; and I have seen one formed by spirting up water from the mouth: it is often seen in cascades, the foaming of the waves of the sea, in fountains, and even in the dew on the grass.

Dr. Langwith has described a rainbow, which he saw lying on the ground, the colours of which were almost as lively as those of the common rainbow. It was extended several hundred yards; and the colours were so strong, that it might have been seen much farther, if it had not been terminated by a bank, and the hedge of a field.

Rainbows have also been produced by the reflection of the sun's beams from a river; and Mr. Edwards describes one, which must have been formed by the exhalations of the city of London, when the sun had been set twenty minutes.

CONVERSATION XX.

Of the Refracting Telescope.

T. We may now, as you are at leisure, proceed to describe the structure of telescopes, of which there are two kinds, viz. the *refracting* and the *reflecting* telescope.

C. The former, or *refracting* telescope, depends, I suppose, upon *lenses* for the operation; and the *reflecting* telescope acts chiefly by means of *mirrors*.

T. Yes: these are the general grounds of the distinction; and we shall devote this morning to the explanation of the *refracting* telescope. Here is one completely fitted up.

J. It consists of two tubes and two glasses.

T. The tubes are intended to hold the glasses, and to confine the boundary of the view. I will therefore explain the principle by the following figure, in which is represented the

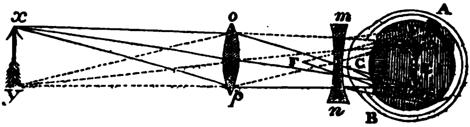


Fig. 40.

eye A B, the two lenses *m n o p*, and the object, *x y*. The lens *o p*, which is nearest the object, is called the object-glass, and that *m n*, nearest to the eye, is called the eye-glass.

C. Is the object-glass a double convex, and the eye-glass a double concave?

T. It happens so in this particular instance, but it is not necessary that the eye-glass should be concave; the object-glass must, however, in all cases, be convex.

C. I see exactly, from the figure, why the eye-glass is concave: for the convex lens converges the rays too quickly, and the focus by that glass alone would be at E; and therefore the concave is put near the eye to make the rays diverge so much as to throw them to the retina before they come to a focus.

T. But that is not the only reason: by coming to a focus at E, the image is very small, in comparison of what it is when the

image is formed on the retina, by means of the concave lens. Can you, James, explain the reason of all the lines which you see in the figure?

J. I think I can; there are two pencils of rays flowing from the extremities of the arrow, which is the object to be viewed. The rays of the pencil flowing from *x* go on diverging till they reach the convex lens *o p*, when they will be so refracted, by passing through the glass, as to converge and meet in the point *x*. Now the same may be said of the pencil of rays which comes from *y*; and, of course, of all the pencils of rays flowing from the object between *x* and *y*. So that the image of the arrow would, by the convex lens, be formed at *z*.

T. And what would happen if there were no other glass?

J. The rays would cross each other and be divergent, so that, when they got to the retina, there would be no distinct image formed, but every point, as *x* or *y*, would be spread over a large space, and the image would be confused. To prevent this, the concave lens *m n* is interposed: the pencil of rays, which would, by the convex glass, converge at *x*, will now be made to diverge, so as not to come to a focus till they arrive at the retina; and the pencil of rays which would by the convex glass have come to a point at *y*, will, by the interposition of the concave lens, be made to diverge so much as to throw the focus of the rays to *b* instead of *y*. By this means the image of the object is magnified.

T. Can you tell the reason why the tubes require to be drawn out more or less for different persons?

C. The tubes are to be adjusted in order to throw the focus of rays exactly on the retina: and, as some eyes are more convex than others, the length of the focus will vary in different persons; and by sliding the tube up and down, this object is obtained.

T. Refracting telescopes are used chiefly for viewing terrestrial objects; two things, therefore, are requisite in them: the first is, that they should show objects in an upright position, that is, in the same position that we see them without glasses; and the second is, that they shall afford a large *field of view*.

J. What do you mean, sir, by a field of view?

T. All that part of a landscape which may be seen at once, without moving the eye or instrument. Now, in looking on the figure again, you will perceive, that the concave lens throws a number of the rays beyond the pupil c of the eye on to the iris on both sides, but those only are visible, or go to form an image, which pass through the pupil; and, therefore, by a telescope made in this way, the middle part of the object only is seen, or, in other words, the prospect is by it very much diminished.

C. How is that remedied?

T. By substituting a double convex eye-glass *g h* instead of the concave one. Here the focus of the double convex lens is at E, and the glass *g h* must be so much more convex than *o p*

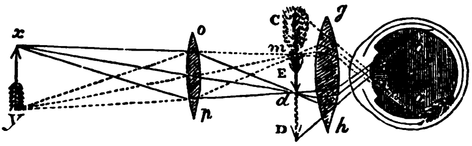


Fig. 41.

as that its focus may be also at E: for then the rays flowing from the object *x y*, and passing through the object-glass *o p*, will form the inverted image *m* E *d*. Now, by interposing the double convex *g h*, the image is thrown on the retina, and it is seen under the large angle D *e* C; that is, the image *m* E *d* will be magnified to the size C E D.

J. Is not the image of the object in the telescope inverted?

T. Yes, it is; for you see the image on the retina stands in the same position as the object; but we always see things by having the images inverted; and, therefore, whatever is seen by telescopes constructed as this is, will appear inverted to the spectator, which is a very unpleasant circumstance with regard to the terrestrial objects; it is on that account chiefly used for celestial observations.

C. Is there any rule for calculating the magnifying power of this telescope?

T. It magnifies in proportion as the focal distance of the object-glass is greater than the focal distance of the eye-glass. Thus, if the focal distance of the object-glass is ten inches, and that of the eye-glass only a single inch, the telescope magnified the *diameter* of an object ten times; and the *whole surface* of the object will be magnified a hundred times.

C. Will a small object, as a silver penny for instance, appear a hundred times larger through this telescope than it would by the naked eye?

T. Telescopes, in general, represent terrestrial objects to be *nearer* and not *larger:* thus looking at the silver penny a hundred yards distant, it will not appear to be larger, but at the distance only of a single yard.

J. Is there no advantage gained, if the focal distance of the eye-glass and of the object-glass be equal?

T. None; and, therefore, in telescopes of this kind, we have only o increase the focal distance of the object-glass, and to

diminish the focal distance of the eye-glass, to augment the magnifying power to almost any degree.

C. Can you carry this principle to any extent?

T. Not altogether so: an object-glass of ten feet focal distance will require an eye-glass whose focal distance is rather more than two inches and a half; and an object-glass with a focal distance of a hundred feet must have an eye-glass whose focus must be about six inches from it. How much will each of these glasses magnify?

C. Ten feet divided by two inches and a half give for a quotient forty-eight; and a hundred feet divided by six inches give two hundred: so that the former magnifies forty-eight times, and the latter two hundred times.

T. Refracting telescopes, for viewing terrestrial objects, in order to show them in their natural posture, are usually constructed with one object-glass and three eye-glasses, the focal distance of these last being equal.

J. Do you make use of the same method in calculating the magnifying power of a telescope constructed in this way, as you did in the last?

T. Yes; the three glasses next the eye having their focal distances equal, the magnifying power is found by dividing the focal distance of the object-glass by the focal distance of one of the eye-glasses. We have now said as much on the subject as is necessary to our plan.

C. What is the construction of opera-glasses, that are so much used at the theatre?

T. The opera-glass is nothing more than a short refracting telescope.

The *night* telescope is only about two feet long; it represents objects inverted, much enlightened, but not greatly magnified. It is used to discover objects, not very distant, but which cannot otherwise be seen for want of sufficient light.

The *transit* instrument is a refracting telescope permanently fixed in the direction north and south; its axis is conical and hollow, and is firmly supported on stone columns. It is directed to the south, and, consequently, to the meridian; it has free motion up and down *in* the meridian, but cannot be moved out of it. It is used for observing the transits of stars, or their passage past the meridian. Within the tube are *five*, *seven*, or *nine* vertical lines, constructed of spider web or fine platinum wire, and *one* horizontal line. The stars are watched as they pass these lines, and the times are noted. As very few stars, even with the best object-glasses, can be seen by day, this instrument is mostly used at night.

C. But how can the fine threads be seen in the dark?

T. I was about to tell you, that a lamp is placed opposite the hollow axle; its light is received by a reflector placed within the tube of the telescope, but not in the way of the view; thence it is reflected so as either to illuminate the whole field of view and leave the wires as dark lines, or to illuminate the wires and leave the field of view dark, and to give any intermediate amount of illumination. The simplest mode of effecting these various illuminations is contrived by Mr. Simms, who made the mirror movable, and furnished it with reflecting prisms.

CONVERSATION XXI.

Of Reflecting Telescopes.

T. This is a telescope of a different kind, and is called a *reflecting* telescope.

The great inconvenience attending refracting telescopes is their length, and, on that account, they are not very much used when high powers are required. A reflector of six feet long will magnify as much as a refractor of a hundred feet.

J. Are these, like the refracting telescopes, made in different ways?

T. They were invented by Sir Isaac Newton, but have been greatly improved since his time. The following figure will lead

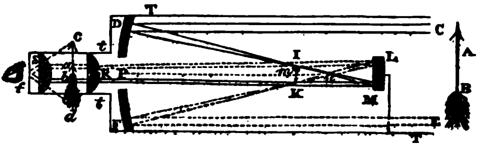


Fig. 42.

to a description of one of those most in use. T T represents the large tube, and *t t* the small tube of the telescope, at one end of which is D F, a concave mirror, with a hole in the middle at P, the principal focus of which is at I K; opposite to the hole P is a small mirror L, concave towards the great one; it is fixed on a strong wire M, and may, by means of a long screw on the outside of the tube, be made to move backwards or forwards. A B is a remote object; from which rays will flow to the great mirror D F.

J. And I see you have taken only two rays of a pencil from the top, and two from the bottom.

T. And in order to trace the progress of the reflections and refractions, the upper ones are represented by full lines, the lower ones by dotted lines. Now the rays at C and E falling upon the mirror upon D and F, are reflected, and form an inverted image at *m*.

C. Is there anything there to receive the image?

T. No: and therefore they go on towards the reflector L, the rays from different parts of the object crossing one another a little before they reach L.

J. Does not the hole at P tend to distort the image?

T. Not at all; the only defect is that there is less light. From the mirror L the rays are reflected nearly parallel through P; there they have to pass the plano-convex lens R, which causes them to converge at *a b*, and the image is now painted in the small tube near the eye; and having brought the image of the object so nigh as at *a b*, we magnify it by the plano-convex lens S. It will appear as large as *c d*, that is, the image is seen under the angle *c f d*.

C. How do you estimate the magnifying power of the reflecting telescope?

T. The rule is this: "Multiply the focal distance of the large mirror by the distance of the small mirror from the image *m*: then multiply the focal distance of the small mirror by the focal distance of the eye-glass; and divide these two products by one another, and the quotient is the magnifying power."

J. It is not likely that we should know all these in any instrument we possess.

T. The following, then, is a method of finding the same thing by experiment: "Observe at what distance you can read any book with the naked eye, and then remove the book to the farthest distance at which you can distinctly read by means of the telescope, and divide the latter by the former."

The powers of different telescopes may be readily tried and compared, by looking at double stars, and observing whether, and how far, they separate them. This refers to telescopes of high powers.

C. Had not the late Dr. Herschel a very large reflecting telescope?

T. He made many, but the tube of his grand telescope was nearly 40 feet long, and 4 feet 10 inches in diameter. The concave surface of the great mirror is 48 inches of polished surface in diameter, and it magnifies 6000 times. This noble instru-

ment cost the Doctor four years' severe labour; it was finished August 28. 1789, on which day was discovered the sixth satellite of Saturn.

C. I should like to know what Newton's original arrangement was.

T. Instead of looking in at the small mirror, through a hole in the larger one, he placed the small one at an angle, and looked in at it through a hole in the side of the tube.

C. What is an achromatic telescope?

T. Do you remember your having observed coloured figures around every object that you viewed with the pocket telescope which your cousin purchased at the fair? Now these coloured figures appear in a greater or less degree about objects viewed with all ordinary telescopes; they arise from what is termed *chromatic aberration.* If you look at a lense edgewise, you will see that it is really two prisms, joined at their bases in the convex, and at their points in the concave, and then rounded off. Now prisms analyse light into its component colours; and so do lenses, though not to so great an extent, because they are not prisms of the most favourable form. But by making a compound lens of a flint-glass concave lens, and a crown glass convex lens, the dispersive powers nearly neutralize each other, and an almost colourless object is obtained. Dr. Blair obtained a perfectly achromatic lens by confining muriatic acid between two lenses of flint-glass.

C. Was Herschel's the largest telescope ever made?

T. Until very lately it was. But it is now far surpassed by the monster telescope made by Lord Rosse. The reflector is six feet in diameter; it is made of an alloy of copper and tin, in the proportion of 126·4 of the former to 58·9 of the latter. These numbers represent the atomic weights or combining equivalents of these two metals; but you will understand these terms better when we talk on chemical science. It is of the enormous weight of three tons. By immense perseverance, joined to very great ingenuity, the noble philosopher overcame a host of apparently insurmountable difficulties, and arrived at absolute certainty in casting perfect specula. The machine by which the surface was ground and polished is another illustration of first-rate mechanical ingenuity. The tube of the telescope is 56 feet long; the focal length of the speculum 52 feet. The diameter of the tube is seven feet; it is made of inch-deal hooped with iron. It is fixed to solid masonry by a universal joint; and by means of walls, and scaffolds, and ropes, and counterpoises, it can be directed to every requisite point of the heavens.

C. And what discoveries have been made with this instrument?

T. His lordship has not published his unfinished researches; but several facts have come to us. Its magnifying power is so great, that objects soon pass from the field of view. The most startling proof of its superiority is the great quantity of light it presents; so that many lunar phenomena which had not been seen before have now presented themselves. Lord Rosse's great expectations are in the examination of double stars and nebulæ.

C. What are nebulæ?

T. The milky way is a nebula, or cloud of stars, of which our sun is one; but out beyond this system are numerous other systems, which, under ordinary powers, appear merely as a mist, or nucleus of light; higher powers have resolved most of them into stars: but there are some that have still maintained their nebulous character under the highest powers that have been employed; so much so, that some philosophers have been induced to think that creative power is first manifested in the production of nebulous matter; and that these gradually concentrate and become consolidated into suns or planets. But the revelations of Lord Rosse's telescope tend to the overthrow of this theory.

C. Can you tell us any more about this glorious instrument?

T. The whole was executed at the sole expense of this spirited and talented nobleman, in his own laboratory and workshops at Parsonstown, immediately under his own eye, by artisans instructed by himself. It cannot have cost less than twelve thousand pounds, besides the large sums that have been sunk in unsuccessful experiments. The character given of his lordship is, "talent to divine—patience to bear disappointment—perseverance—profound mathematical knowledge—mechanical skill—uninterrupted leisure from other pursuits;" all of which are brought to bear by his having "a great command of money." I should mention that he made first a three-feet reflecting telescope.

CONVERSATION XXII.

Of the Microscope—Its Principle—Of the Single Microscope—Of the Compound Microscope—Of the Solar Microscope.

T. We are now to describe the microscope, which is an instrument for viewing very small objects. You know that, in general, persons who have good sight cannot distinctly view an object at a nearer distance than about six or eight inches.

C. I cannot read a book at a shorter distance than this; but if I look through a small hole made with a pin or needle in a sheet of brown paper, I can read at a very small distance indeed.

T. You mean, that the letters appear, in that case, very much magnified, the reason of which is, that you are able to see at a much shorter distance in this way than you can without the intervention of the paper. Whatever instrument or contrivance can render minute objects visible and distinct is properly a microscope.

J. If I look through the hole in the paper, at the distance of five or six inches from the print, it is not magnified.

T. The object must be brought near to increase the angle by which it is seen; this is the principle of all microscopes, from the single lens to the most compound instrument. A is an object

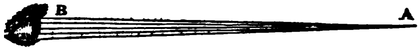


Fig. 43.

not clearly visible at a less distance than A B; but if the same object be placed in the focus of a lens, the rays which proceed from it will become parallel, by passing through the said lens;

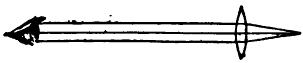


Fig. 44.

and therefore the object is distinctly visible to the eye if placed anywhere before the lens. There are four distinctions in microscopes: the single, the compound, the solar, and the oxy-hydrogen.

C. Does the single microscope consist only of a lens?

T. By means of a lens, a great number of rays proceeding from a point are united in the same sensible point; and as each ray carries with it the image of the point from whence it proceeded, all the rays united must form an image of the object.

J. Is the image *brighter* in proportion as there are more rays united?

T. Certainly: and it is more distinct in proportion as their natural order is preserved. In other words, a single microscope or lens removes the confusion that accompanies objects when seen very near by the naked eye; and it magnifies the diameter of the object, in proportion as the focal distance is less than the limit of distinct vision, which we may reckon from about six to eight inches.

C. If the focal distance of a reading-glass be four inches, does it magnify the diameter of each letter only twice?

T. Exactly so; but the lenses used in microscopes are often not more than $\frac{1}{4}$, or $\frac{1}{8}$, or even $\frac{1}{20}$ of an inch radius.

J. And in a double convex the focal distance is always equal to the radius of convexity.

T. Then tell me how much lenses of $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{20}$ of an inch will each magnify.

J. That is readily done: by dividing 8 inches, the limit of distinct vision, by $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{20}$.

C. And to divide a whole number, as 8, by a fraction, as $\frac{1}{4}$, &c., is to multiply the said number by the denominator of the fraction: of course, 8 multiplied by 4 gives 32; that is, the lens whose radius is $\frac{1}{4}$ of an inch magnifies the diameter of the object 32 times.

J. Therefore the lenses of which the radii are $\frac{1}{8}$ and $\frac{1}{20}$, will magnify as 8 multiplied by 8, and 8 multiplied by 20; that is, the former will magnify 64 times, the latter 160 times, the diameter of an object.

T. You see, then, that the smaller the lens, the greater its magnifying power. Dr. Hooke says, in his work on the microscope, that he has made lenses so small, as to be able, not only to distinguish the particles of bodies a million times smaller than a visible point, but even to make those visible of which a million times a million would hardly be equal to the bulk of the smallest grain of sand.

C. I wonder how he made them.

T. I will give you his description: he first took a very narrow and thin slip of clear glass, melted it in the flame of a candle or lamp, and drew it out into exceedingly fine threads. The end of one of these threads he melted again in the flame, till it ran into a very small drop, which, when cool, he fixed in a thin plate of metal, so that the middle of it might be directly over the centre of an extremely small hole made in the plate. Here is a very convenient single microscope.

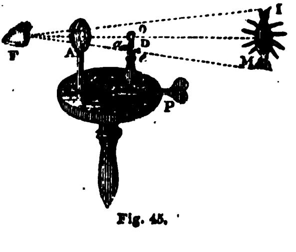


Fig. 45.

J. It does not seem, at first sight, so simple as those which you have just now described.

T. A is a circular piece of brass, or it may be made of wood, ivory, &c., in the middle of which is a very small hole; in this is fixed a small lens, the focal distance is O D; at that distance is a pair of pliars D E, which may be adjusted

by the sliding screw E, and opened by means of two little studs *a e;* with these any small object may be taken up and viewed with the eye placed at the other focus of the lens at F, to which it will appear magnified, as at I M. Let us now look at a double or compound microscope.

J. How many glasses are there in this?

T. There are two; and the construction of it may be seen by this figure; *c d* is called the object-glass, and *e f* the eye-glass. The small object *a b* is placed a little farther from the glass *c d* than its principal focus, so that the pencils of rays flowing from the different points of the object, and passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where the image of the object will be formed. This image is viewed by the eye-glass *e f*, which is so placed that the image *g h* may be in the focus, and the eye at about an equal distance on the other side; the rays of each pencil will be parallel, after going out of the eye-glass, as at *e* and *f*, till they come to the eye at *k*, by the humours of which they will be converged and collected into points on the retina, and form the large inverted image A B.

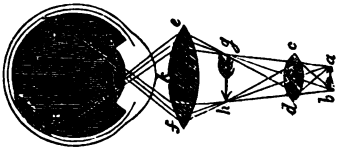


Fig. 46.

C. Pray, sir, how do you calculate the magnifying power of this microscope?

T. There are two proportions, which, when found, are to be multiplied into one another: 1st, as the distance of the image from the object-glass is *greater* than its distance from the eye-glass; and 2nd, as the distance from the object is *less* than the limit of distinct vision.*

Example 1. If the distance of the image from the object-glass be 4 times greater than from the eye-glass, the magnifying power of 4 is gained; and if the focal distance of the eye-glass be one inch, and the distance of distinct vision be considered at 7 inches, the magnifying power of 7 is gained, and 7×4 gives 28; that is, the diameter of the object will be magnified 28 times, and the surface will be magnified 784 times.

J. Do you mean that an object will, through such a microscope, appear 784 times larger than by the naked eye?

* The late Professor Vince gave the following rule for finding the linear magnifying power of a compound microscope:—"It is equal to the least distance of distinct vision, multiplied by the distance of the image from the object-glass, divided by the distance of the object from the object-glass, multiplied by the focal length of the eye-glass."

T. Yes, I do; provided the limit of distinct vision be 7 inches; but some persons who are short-sighted, can see as distinctly at 5 or 4 inches as another can at 7 or 8; to the former, the object will not appear so large as to the latter.

Example 2. What will a microscope of this kind magnify to three different persons, whose eyes are so formed as to see distinctly at the distance of 6, 7, and 8 inches, by the naked eye: supposing the image of the object-glass to be five times as distant as from the eye-glass, and the focal distance of the eye-glass be only the tenth part of an inch?

C. As five is gained by the distances between the glasses, and 60, 70, and 80 by the eye-glass, the magnifying powers will be as 300, 350, and 400.

J. How is it that 60, 70, and 80 are gained by the eye-glass?

C. Because the distances of distinct vision are put at 6, 7, and 8 inches, and these are to be divided by the focal distance of the eye-glass, or by $\frac{1}{10}$: but, to divide a whole number by a fraction, we must multiply that number by the denominator, or lower figure in the fraction; therefore, the power gained by the distance between the two glasses, or 5, must be multiplied by 60, 70, or 80. And the surface of the object will be magnified in proportion to the square of 300, 350, or 400, that is, as 90,000, 122,500, or 160,000.

T. We now come to the solar microscope, which is by far the most entertaining of them all, because the image is much larger, and, being thrown on a sheet, or other white surface, may be viewed by many spectators at the same time, without any fatigue to the eye. Here is one fixed in the window-shutter; but I can explain its construction best by a figure.

J. There is a looking-glass on the outside of the window.

T. Yes, the solar microscope (see fig. 47.) consists of a

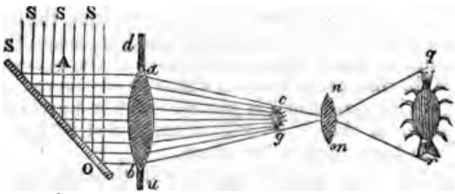


Fig. 47.

looking-glass s o without, the lens *a b* in the shutter *d u*, and the lens *n m* within the dark room. These three parts are united to and in a brass tube. The looking-glass can be turned

by the adjusting screw so as to receive the incident rays of the sun s s s, and reflect them through the tube into the room. The lens *a b* collects those rays into a focus at *n m*, where there is another magnifier; here, of course, the rays cross, and diverge to the white screen, on which the image of the object will be painted.

C. I see the object is placed a little behind the focus.

T. If it were in the focus it would be burnt to pieces immediately. The magnifying power of this instrument depends on the distance of the sheet or white screen; perhaps about ten feet is as good a distance as any. You perceive, that the size of the image is to that of the object as the distance of the former from the lens *n m* is to that of the latter.

J. Then the nearer the object to the lens, and the farther the screen from it, the greater the power of this microscope.

T. You are right; and if the object be only half an inch from the lens, and the screen nine feet, the image will be 46,656 times larger than the object; do you understand this?

C. Yes; the object being only half an inch from the lens, and the image 9 feet or 108 inches, or 216 half inches, the diameter of the image will be 216 times larger than the diameter of the object, and this number multiplied into itself will give 46,656.

T. This instrument is calculated only to exhibit transparent objects, or such as the light can pass through in part. For opaque objects, a different microscope is used; and, indeed, there is an almost endless variety of microscopes. But the solar microscope is now seldom used; for as it depends on the shining of the sun for light, in this variable climate of ours it is almost certain of being useless when most needed. The oxy-hydrogen microscope is now used. In this, instead of sunlight, the powerful light, produced by allowing a lighted jet of the mixed gases oxygen and hydrogen to play upon lime, is used. In other respects, the general construction of the instrument is the same. The perfection to which this instrument is brought is marvellous.

CONVERSATION XXIII.

Of the Camera Obscura, Magic Lantern, and Multiplying Glass, &c.

T. We may now converse upon some miscellaneous subjects, of which the first shall be the *camera obscura.*

C. What is a camera obscura?

T. The meaning of the term is a darkened chamber; the construction of it is very simple, and will be understood in a moment by you, who know the properties of the convex lens.

A convex lens, placed in a hole in a window-shutter, will exhibit, on a white sheet of paper placed in the focus of the glass, all the objects on the outside, as fields, trees, men, houses, &c., in an inverted order.

J. Is the room to be quite dark, except the light which is admitted through the lens?

T. It ought to be so; and, to have a very interesting picture, the sun should shine upon the objects.

J. Is there no other kind of camera obscura?

T. A portable one may be made with a square box, in one side of which is to be fixed a tube, having a convex lens in it: within the box is a plane mirror reclining backwards from the tube, in an angle of forty-five degrees.

C. On what does this mirror reflect the image of the object?

T. The top of the box is a square of unpolished glass, on which the picture is formed. And if a piece of oiled paper be stretched on the glass, a landscape may be easily copied; or the outline may be sketched on the rough surface of the glass.

J. Why is the mirror to be placed at an angle of 45 degrees exactly?

T. The image of the objects would naturally be formed at the back of the box opposite to the lens; in order, therefore, to throw it on the top, the mirror must be so placed, that the angle of incidence shall be equal to the angle of reflection. In the box, according to its original make, the top is at right angles to the end, that is, at an angle of 90 degrees, therefore, the mirror is put at half 90, or 45 degrees.

C. Now, the incident rays falling upon a surface, which declines to an angle of 45 degrees, will be reflected at an equal angle of 45 degrees, which is the angle that the glass top of the box bears with respect to the mirror.

C. Is the tube in this machine fixed?

T. No; it is made to draw out or push in, so as to adjust the distance of the convex glass from the mirror, in proportion to the distance of the outward objects, till they are distinctly painted on the horizontal glass.

C. Has any real use been made of the camera?

T. One of the most happy adaptations of this instrument is in daguerreotype. You remember my telling you that light acted chemically on bodies; a plate of silver having its surface prepared with certain chemicals that are exceedingly susceptible to light, is placed in the focus of a good camera, and the picture,

instead of being evanescent, is so impressed upon the plate, that a slight further chemical process fixes it. The description of the particular methods will form the subject of a subsequent conversation.

J. Will you now explain the structure of the magic lantern, which has long afforded us occasional amusement?

T. This little machine consists, as you know, of a sort of tin box, within which is a lamp or candle; the light of this passes through a great plano-convex lens, placed in a tube fixed in the front. This strongly illuminates the objects, which are painted on slips of glass, and placed before the lens in an inverted position. A sheet, or other white surface, is placed to receive the images.

C. Do you invert the glasses on which the figures are drawn, in order that the images of them may be erect?

T. Yes; and the illumination may be greatly increased, and the effect much more powerful, by placing a concave mirror at the back of the lamp.

C. Did you not tell us that the *phantasmagoria*, which we saw at the Lyceum, was a species of the magic lantern?

T. There is this difference between them: in common magic lanterns, the figures are painted on transparent glass, consequently, the image on the screen is a circle of light having a figure or figures on it; but in the phantasmagoria all the glass is made opaque, except the figure only, which, being painted in transparent colours, the light shines through it, and no light can come upon the screen but what passes through the figure.

J. But there was no sheet to receive the picture.

T. No: the representation was thrown on a thin screen of silk placed between the spectators and the lantern.

C. What caused the images to appear approaching and receding?

T. It is owing to removing the lantern farther from the screen, or bringing it nearer to it; for the size of the image must increase as the lantern is carried back, because the rays come in the shape of a cone; and, as no part of the screen is visible, the figure appears to be formed in the air, and to move farther off when it becomes smaller, and to come nearer as it increases in size.

C. I am sure the dissolving views must be produced by a magic lantern.

T. They are; or rather by two lanterns. They are placed side by side, and just enough out of a parallel to permit their images to fall on the same part of the screen. Suppose you wish to represent an empty cathedral, and then that it shall be gra-

dually filled with worshippers. Two views of the cathedral are painted on glass in transparent colours, one is full of people, the other is empty; one view is placed in each lantern: a couple of screens are fixed as arms to a vertical rod, and they are so arranged that, as the rod is gradually elevated by rackwork, one screen moves in front of one lantern, in proportion as the other moves from the other. So that one view gradually dissolves away, and the other as gradually takes its place.

J. What is the opaque microscope, that so much interested us at the Polytechnic?

T. Very much the same sort of thing as the magic lantern; except that the light, instead of passing through the object, shines upon it, and is reflected off through the lenses, and so onward to the screen. This is shown by the lime-light above mentioned; its success depends on the management of the light, which must be very intense, and in large quantities, but must not be so dispersed by the mirrors, as only to illuminate parts of the object instead of the whole. Mr. Longbottom, the secretary of the Polytechnic, to whom we are indebted for this instrument, has overcome these difficulties. The *physioscope* is the same instrument, employed to depict "the human face divine" in colossal dimensions upon the screen, and is a most amusing illustration of experimental optics. For this, also, we are indebted to Mr. Longbottom. The Kalotrope is a modification of the dissolving views.

J. Here is another instrument, the construction of which you promised to explain—the *multiplying glass.*

T. One side of this glass is cut into many distinct surfaces, and in looking at an object, as your brother, through it, you will see, not one object only, but as many as the glass contains plane surfaces.

I will draw a figure to illustrate this: let A *i* B represent a glass, flat at the side next the eye H, and cut into three distinct surfaces on the opposite side, as A *b*, *b d*, *d* B. The object C will not appear magnified, but as rays will flow from it to all parts of the glass, and each plane surface will refract these rays to the eye, the same object will appear to the eye in the direction of the rays which enter it through each surface. Thus a ray C *i*, falling perpendicularly on the middle surface, will suffer no refraction, but show the object in *its true place* at C; the ray from

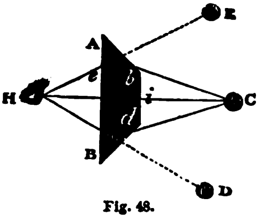


Fig. 48.

C *b*, falling obliquely on the plane surface, A *b*, will be refracted in the direction of *b e*, and on leaving the glass at *e*, it will pass to the eye in the direction *e* H, and therefore it appears at E: and the ray C *d* will, for the same reason, be refracted to the eye in the direction B H, and the object C will appear also at D.

If, instead of three sides, the glass had been cut into 6 or 20, or any other number, there would have appeared 6, 20, &c. different objects, differently situated. If with a glass like this you look at a luminous object, as a candle, and give to the glass a rotatory motion in its own plane, the numerous images of the candle will appear to move round the central image, and thus present a very interesting picture incessantly shifting.

I may mention one more instrument, the *camera lucida*. It is a four-sided prism; one of the angles is a right angle; opposite to this is an angle of 135°; the other two are each 67½°. The prism is so held that the two right sides are, one vertical, the other upward and horizontal: a ray entering the vertical side in a horizontal direction, is reflected first by one short side, and then by the other, so that it escapes from the horizontal side in a vertical direction; and hence if the eye look downwards in this direction, the object appears beneath it; so that if a sheet of paper be placed in this line, the object will appear on the paper, and a person unaccustomed to drawing may readily sketch it.

CONVERSATION XXIV.

On Double Refraction and Polarization of Light.

J. What is that crystal that I see you have carefully placed on your table this morning?

T. It is Iceland spar; and I have produced it in order to lead you to certain other phenomena of light. Look through it at the small dot I have made on the paper.

J. You have made two dots, not one—oh, no, you have not, for on removing the crystal, there is evidently but one dot, although there at first seemed to be two.

T. This is termed *double refraction*, and is a property possessed by the generality of crystals, whose primitive form is not a cube or an octohedron. One of the images obeys the common laws of light, and is called the *ordinary* ray; the other is subject to peculiar laws, and is termed the *extraordinary* ray. In some crystals there is but one axis or direction, in which the phenomena of double refraction exist, and these only have the

ordinary ray; in others there are two axes of double refraction, and these present no ordinary ray, properly so called: for no portion of the light that traverses them is subject to the ordinary laws of refraction.

C. I am very curious to know what the other laws may be; for I had thought we knew all the leading laws of light.

T. You are too hasty, my boy: we will arrive at them in due time. This branch of science is termed the *polarization of light.* When a ray of light is reflected at certain angles on polished surfaces, or is refracted by the same bodies, and *then* allowed to pass through a double refracting crystal, it acquires new properties, it ceases to be reflected by other bodies at certain angles, and is not unusually divided into two rays of equal intensities.

J. I do not clearly understand you: this word *polarization* puzzles me.

T. And it has puzzled many a head before yours: it was applied by those who conceived light to be composed of solid particles; they thought these were arranged in certain order, as if they had poles. But now, while that theory is forsaken, the inappropriate word is maintained.

C. Then, if you tell us more clearly some of the characters of polarized light, and a little of its behaviour, we will forget the word, and think of the facts only.

T. If a ray of light falls on a glass surface at an angle of 35° 25′, as, for instance, on a piece of blackened glass lying upon my sloping desk, it will, of course, be reflected towards the ceiling: if I now catch the reflected ray on a second plate of glass, it will be again reflected, unless the second plate be placed at right angles to the ray, so as to reflect it toward the sides of the room. In this case, when the second glass is at the angle of 35° 25′ with the ray, the ray is *not* reflected at all, and is *actually lost.*

J. What made you mention that particular angle?

T. Because I was speaking of glass surfaces; but every reflecting surface has an angle of its own for polarizing light; and this angle bears a certain fixed relation to the refracting index of the body. I should tell you that the ray is not *entirely* lost when ordinary white light is employed, because the refracting angle for each of the rays of the spectrum is not the same; but monochromatic rays are quite darkened.

C. But if the second plate is not placed at the proper angle, what is the result?

T. The ray then obeys the laws of ordinary light: in the two *proper positions* there is *no* second reflection; in the two at right

C. I cannot read a book at a shorter distance than this; but if I look through a small hole made with a pin or needle in a sheet of brown paper, I can read at a very small distance indeed.

T. You mean, that the letters appear, in that case, very much magnified, the reason of which is, that you are able to see at a much shorter distance in this way than you can without the intervention of the paper. Whatever instrument or contrivance can render minute objects visible and distinct is properly a microscope.

J. If I look through the hole in the paper, at the distance of five or six inches from the print, it is not magnified.

T. The object must be brought near to increase the angle by which it is seen; this is the principle of all microscopes, from the single lens to the most compound instrument. A is an object

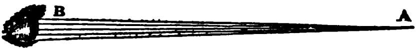


Fig. 43.

not clearly visible at a less distance than A B; but if the same object be placed in the focus of a lens, the rays which proceed from it will become parallel, by passing through the said lens;

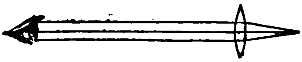


Fig. 44.

and therefore the object is distinctly visible to the eye if placed anywhere before the lens. There are four distinctions in microscopes: the single, the compound, the solar, and the oxy-hydrogen.

C. Does the single microscope consist only of a lens?

T. By means of a lens, a great number of rays proceeding from a point are united in the same sensible point; and as each ray carries with it the image of the point from whence it proceeded, all the rays united must form an image of the object.

J. Is the image *brighter* in proportion as there are more rays united?

T. Certainly: and it is more distinct in proportion as their natural order is preserved. In other words, a single microscope or lens removes the confusion that accompanies objects when seen very near by the naked eye; and it magnifies the diameter of the object, in proportion as the focal distance is less than the limit of distinct vision, which we may reckon from about six to eight inches.

like a gridiron. If it is placed with the laminæ in a horizontal direction, *none of the vertical waves* can pass through: they will be stopped, so that the light, when it emerges on the other side, will only consist of *horizontal* waves. If another piece of agate is placed in the course of these waves, it will allow them to pass through, if it is placed with its laminæ horizontally, as the other was; but if it is turned so that they are vertical, the horizontal waves will be arrested, and all will be dark. So you see that in this simple case *polarization* absorbs one set of waves, and analysation the other.

In cases of perfect double refraction, both sets of waves pass through the crystal; but they are separated from each other, so that an analysing plate would let one set of waves or one ray pass, and would intercept the other.

C. I think we shall be able now to remember the nature of polarized light.

T. Before we part, I have some more facts to mention that will be equally instructive; they refer to what has been termed *coloured polarization.* You remember what I said of *interferences,* when various tints are produced by the reflection of light from thin films. An analogous phenomenon occurs with polarized light; and in this case the thin film is called a *depolarizer.* When thin laminæ of mica, Iceland spar, rock-crystal &c., are placed between the polarizing and the analysing plates, the interferences in the vibrations are produced, and they are manifested by the production of colours: the tint depends on the thickness of the film and the nature of the crystal; if the film is of uniform thickness, the colour is uniform; if it varies, the tints also vary. Selenite, or *hydrated crystal of sulphate of lime,* is extensively employed, on account of the ease with which it is laminated; and by arranging together pieces of various thickness and form, coloured objects, such as birds, flowers, figures, &c., may be exhibited; and when the whole is fitted in tubes and illuminated by the oxy-hydrogen light, the objects may be thrown on a screen, as with the magic lantern.

C. Does any change occur to coloured polarized light, as to ordinary polarized light, by rotating any part of the apparatus?

T. Yes: if the *thin film* is rotated, there are four positions in which the colour is produced, and four in which there is none; if the analyser is rotated, there are also four positions of colour, and four without; but the alternate quadrants or quarters of the circle give complementary colours; so that if the original tint were green, the next quadrant would give red, the next green, and the next red. Hence a red rose with green leaves

would, by a quarter rotation of the analyser, be converted into a green rose with red leaves. If the complementary tints, as, for instance, two circles, are made to overlap each other, white light is produced.

C. Have these curious facts any practical application?

T. They have: for by these means we can discover what bodies possess double refracting properties; for many are possessed of this power, although in so small a degree as not to give double images, like the piece of Iceland spar that I employed at the beginning of our conversation. For instance: Dr. Pereira advises that all optical glass should be examined by the polariscope before using, in order to discover whether it is badly annealed; this is readily detected by polarized light. Polarized light may be used to detect the true character of the various starches; as potato starch, arrow-root, tapioca, wheat starch, rice starch. But I must not talk too deeply on this subject, for I fear to confuse instead of instruct you. All I wish is to give you a few of the leading features of polarized light; so that when on some future day you sit down to study this branch of physics, it may not come upon you as entirely new.

J. Your last words remind me of some observations you made last week, about examining camphine by polarized light, to see if it were good. How could you manage this?

T. The laws by which this would be determined are those of *circular polarization.* I must not confuse you with the deeper parts of the subject; but merely tell you that certain crystals, held in particular directions, as a plate of rock crystal, perpendicular to the axis of refraction, produce circular polarization; that is, rings are apparent round the axis, and a uniform tint occupies the centre: if the plate is rotated, no change occurs; but if the analyser is turned, the tints vary. When homogeneous light is used, similar plates turn the ray in the same direction; but the direction is not the same for all circularly polarizing bodies. If, on turning the analyser from left to right, like the motion of a watch, the order of the colours are *red, orange, yellow, green, blue, indigo,* and *violet,* it is termed *right-handed* polarization; if the same succession occurs on turning from right to left, it is termed *left-handed.* Now many liquids have this property; as volatile essential oils, syrups, solution of camphor, &c. Some are right-handed, others left-handed; and what is very peculiar is that, if you place any one of them in a tube, and look at it at either end, it is in each view right or left-handed, as the case may be: that is to say, if it is right-handed when looked into at one end of the tube, it is right-handed when looked into at the other. The arc of rotation

varies with the liquid under examination, with the degree of concentration if it be a solution, and with the thickness of the film.

C. What apparatus is used in these examinations?

T. The polarizer is generally a black glass: then comes a glass tube of from half a foot to two or three feet in length, contained in a brass tube; and sometimes a few perforated pieces of silver are placed in the glass tube, in order to exclude any reflected light from the sides of the tube. The analyser is a Nichol's prism, or a doubly refracting crystal of calc spar. Homogeneous light is preferred for these examinations; and this is obtained by placing a piece of red glass between the eye and the analyser. The analyser is furnished with an index pointing to a graduated scale: when the trial commences, the index is made to point to 0°; the liquid is now poured in, and the hole at the further end of the instrument appears like two holes; but on turning the analyser a certain distance one way or the other, the extraordinory ray disappears. The angle obtained is the arc of rotation for the given depth of the given substance with the given ray; as examples:

LEFT-HANDED.

	Index.	Thickness of column.	Sp. gr.
Oil of turpentine - - -	45°	6 in.	
Naphtha - - -	12° 40′	6·4	
Grape juice - - -	6°	6·3	
Apple juice - - -	3° 33′	6·3	

RIGHT-HANDED.

	Index.	Thickness of column.	Sp. gr.
Oil of citron - - -	84°	6· in.	
Oil of bergamot - -	29°	6·	
Oil of carraway - -	100°	6·	
Solution of cane sugar in water - - -	23° 5′	6·	1·1052
Ditto - - -	51° 1′	6·	1·2310
Sol. of sugar of milk in water - - -	10° 3′	6·	1·0537
Sol. of sugar of starch in water - - -	48° 5′	6·	1·2459
Sol. of tartaric acid in equal weight of water -	8° 5′	6·3	

C. I see then that in plane polarized light, the maximum and minimum planes are at right angles to each other; whereas, when light is circularly polarized, they are at different angles, according to circumstances.

T. Exactly so; and the angle varies according to the colour of the light employed: it is least with red, and greatest with violet.

J. From what you have said about the action of organic solution on polarized light, it appears that it would not be a very difficult matter to use it as a test.

T. No: and it furnishes a very curious test by which bodies physically different but chemically the same can be distinguished. It actually enables us to look into the very structure of bodies, and, as it were, to feel out their secret nature. And when all ordinary means have failed to detect differences, this singular property of light will find them out and make them manifest.

C. I do think that of all you have yet told us, this strange property of light is the most remarkable.

T. There are many other curious facts connected with it; but as my present desire is merely to give you a rough outline of the subject, I will not say more, but advise you, as you grow older, to read for yourself, and also to take the opportunity presented to you by such institutions as the Polytechnic to see the experiments. Indeed, if you should cease to reside near London, there is scarcely a provincial town that has not its Literary Institution; and few seasons pass without polarized light being selected as the subject of illustration, on account of the facility which the oxy-hydrogen light presents of throwing the brilliant objects upon a screen.

CONVERSATION XXVI.

Chemical Properties of Light.—Sun-Pictures.—Photographs.—Daguerreotype.

T. It had not been my original intention to have introduced any subject into these conversations, which should bear upon Chemistry; for that science is so extensive, that I could not hope to give you much information, without entering into it systematically and somewhat at length. And as we have not here the means of illustrating it by experiment, I would prefer your attending a complete course of lectures. But I have had occasion, when describing the stereoscope, to mention daguerreotypes and photographs, and I must try to explain the processes, without entering more than is needful on the forbidden subject.

J. We shall be very glad to have some general description of these processes; for I must confess, that when my sister had her portrait taken, as if by magic, by M. Claudet, I felt very curious on the subject.

T. You are aware that many things alter in appearance, by

exposure to the sunlight or the light of day. Silver, in its various chemical combinations, is most sensitive; and hence has long been employed for marking linen. Marking-ink is nitrate of silver, that is, silver dissolved in nitric acid; not simply dissolved like sugar in water, but by dissolving, united to the acid, so as to produce a new thing, unlike either the metal or the acid in appearance as in properties. It is a white transparent crystal. The act of uniting is called *chemical combination*. These crystals are dissolved in water; a little lamp-black or indian ink is added, so that the liquid may be visible to the eye, and some gum-water is introduced, that the colouring matter may not sink.

J. I have noticed that, when mamma marks the linen, she lays it on the lawn in the sun.

T. She does; and in so doing, she makes a real photographic experiment. The whole art consists in preparing much more highly sensitive salts of silver; in arranging them on metal, on paper, or on glass, and allowing rays of light of various intensities to act upon them until the desired result is obtained; and then taking means to secure and preserve the change that has been produced, and prevent any further change occurring. From the following experiment you will understand the principles on which the art is based; you will see that it is one step onward beyond marking linen.

I have here an ounce vial, which I have filled with pure rain water, and have added to it 50 grains of nitrate of silver, and in this dish I have some salt and water not very strong. We will dip the paper into the salt water, and then dry it with blotting paper; we will now close the shutters, and brush some of the silver solution over one side of the paper, and dry it in the dark.

C. Why do this in the dark?

T. Because the action of daylight will blacken the paper now covered with a sensitive salt of silver. The paper thus prepared is photographic paper, and is the commencement of the discoveries of Mr. Fox Talbot, first made known in January 2. 1839. Gather a leaf from the vine; lay it on the prepared paper; press it down with a piece of glass, to keep it close and in its place; and let us come to the window and expose it to the sun for a few minutes. Now examine the result by the light of a candle in the darkened room.

C. Dear me! we have made a perfect picture of the leaf. All the veins are distinctly traced out in light lines, and the more transparent parts are darker.

T. In fact, where no light passed, on account of the thickness of the fibre, no change has occurred; and the more the light passed, as in the semi-transparent parts of the leaf, the deeper

is the tint; while around the leaf, where there was nothing to intercept the rays, the paper is quite darkened.

J. But still I do not see that such a picture as this is worth much; for it is very clear that, in order to have the benefit of such pictures, we must keep them in a dark room, and only look at them by candlelight; which would be very inconvenient.

T. It would; but if you now well wash the picture in salt and water, it will destroy all further sensitiveness in the paper, and the picture will remain permanent, while the rest of the paper will be unchangeable, when exposed to light. — I ought here to tell you that the common salt, in this experiment presented to the nitrate of silver, had produced another compound of silver, called *chloride of silver*, and which is more sensitive than the nitrate. When you have learned more of chemistry, you will better understand how these chemical changes are brought about, so as to produce new compounds.

As a contrast to marking-ink, and to this primitive photographic paper, a process has lately been discovered by Mr. Talbot, and which I will describe presently, for producing a surface so sensitive that the picture is produced in the short fraction of a second during which an electric spark exists, and by the light itself of the spark.

C. Will you describe to us some of the more sensitive papers, and tell us of some of their applications.

T. At the Royal Observatory, Greenwich, it is no longer necessary to watch hour by hour the changes in the indications of certain instruments, as the barometer, the thermometer, the magnets, &c. as was formerly the case; but light and photographic paper do the work, and leave the assistants at liberty to attend to other duties. The arrangements employed are the invention of Mr. Brooke. To 4 grs. of isinglass is added, little by little, 1 oz. of boiling distilled water; and the solution is then boiled. To this, when filtered, are added 12 grs. of bromide of potassium, and 8 grs. of iodide of potassium. One side of the paper is washed with this solution, and quickly dried by a fire, and may be kept in the dry for use for two months.

A solution is made of 50 grs. of nitrate of silver in 1 oz. of water; and the one side of the paper is washed with this when required for use. This operation must be done in a darkened room, and with a yellow light.

J. But why a yellow light, rather than any other colour?

T. I have in a previous conversation explained to you, that white light is compounded of seven colours. It has been found that the violet ray has the greatest chemical power; and that the yellow ray has little or none; so that, while it furnishes

light enough to guide us in these operations, it produces no chemical change in the sensitive paper. The vine-leaf would be very quickly impressed on this paper, but will not be visible to the eye until washed in a mixture consisting of a few drops of acetic acid, added to an ounce of saturated solution of gallic acid, which must be done in the dark or yellow light; and before daylight is admitted, the paper must be washed in a solution of 1 drachm of hyposulphite of soda in 5 oz. of distilled water, in order to fix the picture. It is finally washed in clean water.

C. You have mentioned many chemicals, of which I never heard before; and I should not know how to prepare them, if I wished to have some of this paper.

T. It is not necessary; for they are all well known, and are to be purchased prepared for these purposes. In observing the thermometer, a sheet of this paper is fixed on a cylinder that revolves by a clock movement in 24 hours. The thermometer is placed between the paper and a gas-light; and the light is so screened and directed that the mercury of the instrument is in the direct course of the ray, and intercepts it. If the mercury reached the top of the tube, no light could arrive at the paper; and, in proportion as the mercury rises or falls, the light reaches less or more of the paper, and makes a trace.

C. I quite see this; the mercury is like the fibre of the leaf, and when in the way of the light, the paper is unchanged.

T. Mr. Muller of Patna, in India, has described a still more sensitive paper. He puts 15 grs. of nitrate of lead into 1 oz. of water, and floats the paper in this. He then places it for two minutes in a solution of 10 grs. of iodide of iron in 1 oz. of water, and blots it. While moist, he treats it with a solution of 100 grs. of nitrate of silver to 1 oz. of water. The picture on this paper is instantaneous, and is fixed by a solution of hyposulphite of soda.

J. It has occurred to me that, after all, these pictures are all reversed; the lights and shades exchange places, and we have a false result.

T. These original pictures are called *negative photographs;* and in cases where it is necessary that the lights and shades should be true, *positive* pictures are taken by means of these negatives. The negative is made transparent by white wax or albumen, and is pressed upon other prepared paper, and exposed to the light, when a true picture is obtained. But effective though this process may be in many cases, it is not essentially good; for, under the best of circumstances, the paper is indifferently transparent, and hence there is a cloudiness in the result that is not always acceptable.

Negatives have lately been taken on glass, first by M. Niepce, which is thus prepared. Two tea-spoonfuls of solution of isinglass are added to the whites of three eggs, and 15 grs. of iodide of potassium are added thereto. Some of this is spread uniformly over a plate of glass, and is dried for use. When wanted, it is breathed on, and dipped in a solution of 10 grs. of nitrate of silver in 1 oz. of distilled water. When dry, it has a second bath of nitrate of silver, containing a little gallic acid, or sulphate of iron. The picture is brought out by washing in solution of gallo-nitrate of silver, and fixed by a solution of 10 grs. of bromide of potassium in an ounce of water.

Mr. Talbot's "instantaneous" method, to which I referred just now, is on albumenized glass. The glass is coated with a mixture of equal parts of white of egg and water; it is dipped into solution of 3 grs. of nitrate of silver to 1 oz. of strong alcohol and water; the plate is then dipped in a mixture of 1 measure of proto-iodide of iron, 1 of acetic acid, and 10 of alcohol, that has been kept a day or two. The plate is then dipped for use in a mixture of 3 oz. of water, with 70 grs. per oz. of nitrate of silver; and 2 oz. of acetic acid. The picture is developed by a mixture of three parts water to one part saturated solution of proto-sulphate of iron, and is fixed with hypo-sulphite of soda.

C. How many new names we have now heard! I fear we shall have much trouble in remembering them; so I have written them down, and intend referring to papa's "Brande's Chemistry" to learn a little more of their nature.

T. I have two more names to introduce to you,—collodion and pyro-gallic acid.

C. I have seen collodion; for when I cut my finger last week, it was placed on the wound, and produced a thin film.

T. Collodion is gun-cotton dissolved in ether. Gun-cotton is obtained by immersing cotton in a mixture of equal parts by weight of nitric and sulphuric acid, and then well washing it and drying it. One ounce of gun-cotton, dissolved in seven ounces of sulphuric ether, produces a mucilaginous solution of collodion. Iodide of silver is dissolved to saturation in solution of iodide of potassium, and is then gradually mixed with the collodion. The mixture is merely poured over the glass plate and drained off, so that the surface remains smooth. The plate in this state is immediately to be dipped into a solution of 30 grs. of nitrate of silver to 1 oz. of water, and is used immediately and while moist. The picture is developed by a solution of 3 grs. of pyro-gallic acid, and 1 drachm of glacial acetic acid to 1 oz. of water; and is fixed by immersion in a saturated solution of hy-

po-sulphite of soda. Portraits may be taken with the camera (using this process) in from 3 to 30 seconds.

C. The camera that M. Claudet employed was a much more complicated instrument than the one you described in our twenty-third Conversation.

T. The discovery of the photographic art has called forth all the ingenuity of opticians; and the camera has been brought to great perfection. Mr. Beard has a patented camera, in which the image is received on a concave mirror, and reflected thence to its destination; but there are inconveniences attached to it, and it is not much used. The usual plan is to receive the image at the back of the camera, which is generally provided with a plate of ground glass, in order to show the image for adjusting the focus, before commencing operations. The lenses are the most important part. Voigtlander's (of Vienna) are in high repute; for 12 in. pictures, a set of the best lenses is worth 45*l.* They are achromatic; that is, are compounded of flint and crown glass, so as to produce no fringes of colour. They are about 4¼ in. in diameter, and have a focal distance of 10 in. The lens of the best camera at the Great Exhibition (Ross's) is thus described: — " It is furnished with a double achromatic object-lens, about 3 in. aperture; there is no stop, and no part of the field employed which does not receive plenty of light, so that the corners, as well as the middle of the picture, are well illuminated. The field is flat, and *the image is very perfect up to the edges.*"

J. I have noticed that extreme care has been taken to make the paper very sensitive; and I judge from your last remarks that the grand points in the camera are to give a well defined and correct image, and to let as much light as possible pass, not merely to any one part of the picture, but to every part.

T. I am glad to see that you have paid attention and profited by my explanations. Small pictures are readily illuminated equably; but all the skill of the mathematician and of the optician are required to construct apparatus for larger pictures. The largest photographic camera (Plagniol's) in the Exhibition had a 2 ft. square picture-surface; but the space illuminated by the whole of the object-glass was only 6½ in. square. It is said that some French cameras have picture-surfaces of nearly a yard in length.

C. You have not yet described to us the process of daguerreotype. For these pictures are on metal plates, not on paper.

T. I cannot venture to give you more than a general idea of these arts; but must refer you to one or other of the excellent handbooks on Photogenic Manipulation, where you will find

minute details upon all the stages of the processes, and will see that the final success depends on a rigid attention to rules and on careful manipulation. The daguerreotype, like photography, depends on the action of the sun upon sensitive salts of silver. In this case, instead of being presented on the surface of paper, the compounds are formed on the silver surface of a metal plate. Copper plated with silver forms the plate, which is cleaned and polished with extreme care. The clean plate is placed over a pan containing a few crystals of iodine, and then over a pan containing a solution of bromine. Much care and experience are required in the operations of "iodizing" and "bromining." Processes are known in which these substances are simultaneously presented, and sometimes also in union with other accelerating bodies. The plate now made sensitive is ready for the camera, and should produce a portrait in bright weather in ten or twelve seconds. Arrangements are prepared for shutting the plate in a frame impervious to light, before removing it from the camera. It is then introduced into a box, where it is exposed to vapours of mercury, which are made to rise by the heat of a lamp. The mercury condenses on the plate, and reveals the picture. The sensitive surface is finally removed from the rest of the plate, by washing it with a solution of 1 oz. of hypo-sulphite of soda in a pint of water; and it is finished off by washing in hot distilled water, which is carefully drained off, so as to leave no stain. In conclusion, I should tell you that the French government gave Daguerre an annuity of 250*l*., since increased to 446*l*.; and to Niepce an annuity of 166*l*., on condition that they should make public their discovery, which they did, and so made it the property of the world. Notwithstanding this, it has in some way been made the subject of patents in England.

Mr. Talbot, who has been largely concerned in bringing to perfection the photographic art, and who has several patents for his discoveries, in the summer of 1852 freely presented his patents to the public, reserving only portrait-taking, for which many licenses were out, and which could not well be recalled.

The public are now at liberty freely to use the art in all other respects, and are now able each for himself to introduce and to use such improvements as cannot fail to present themselves in the course of personal experience.

C. I have observed that some daguerreotype portraits are coloured; is this done by the action of light?

T. No; it is the work of an artist, who, after the sun picture is completed, applies coloured powders to such parts as he wishes to tint. It is confidently believed, however, that the

time is not far distant, when the sun will take the picture, and tint it also in its true colours. In Nov. 1852, M. Niepce described the success that had hitherto been attained by him, but has not yet given the details. He has operated on a doll dressed in different coloured stuffs, and with gold and silver lace. He has obtained all the colours, and the metallic lustre of the lace; and has also copied rock-crystal, alabaster and porcelain with their peculiar lustres. The silver plates are said to be prepared with chloride of copper.

A Photographic Society has been formed in London since the patents have been presented to the public by Mr. Talbot, and the art is now in a fair way to make large progress.

MAGNETISM.

CONVERSATION I.

Tutor—Charles—James.

Of the Magnet—Its Properties—Useful to Mariners, and others—Iron rendered Magnetic—Properties of the Magnet.

T. You see this dark brown mineral body; and that it has the property of attracting needles and other small iron substances.

J. Yes, it is, I believe, a loadstone, or natural magnet; but you told us that it possessed a much more important property than that of attracting iron and steel.

T. It has what is called the *directive property*, by which mariners are enabled to conduct their vessels through the mighty ocean out of the sight of land; miners are guided in their subterranean paths, and the traveller through deserts otherwise impassable.

C. Were mariners unable to make long and very distant voyages till this property of the magnet was discovered?

T. Till then, they contented themselves with mere coasting voyages: seldom trusting themselves from the sight of land.

J. How long is it since this property of the magnet was first known?

T. It is rather uncertain: it has been thought to have no earlier origin than five or six hundred years ago; but mention is made of it in old Norman poems of the 12th century, and also in an Icelandic history of the 11th century. There is also indubitable evidence that the Chinese were acquainted with it long before the commencement of the Christian era. In the 11th century before Christ, mention is made of cars being employed for discovering the bearings of a place, which cars are repeatedly called *indicators of the south*. As early as the beginning of the second century of our era, we find the means employed to be "a stone with which the needle is directed."

C. You have not told us in what the discovery consists.

T. When a magnet, or a needle rubbed with a magnet, is freely suspended, it always assumes a certain direction; one end

points *towards* the north, but not exactly to the north, except in a few places on the earth.

J. Is that a magnet which is fitted to the bottom of the globe, and by means of which we set the globe in a proper direction, with regard to the cardinal points, north, south, east, and west.

T. That is called a compass, the needle of which is steel magnetised, and it is possessed of the same properties as is the magnet itself.

C. Can any iron and steel be made magnetic?

T. Very soft iron is magnetised to its full extent, immediately on touching a magnet: but it loses the whole of its magnetism on the magnet being removed. Harder iron or steel takes more time receiving magnetism; but then it will retain it after the removal of the magnet. Artificial magnets may be rendered more powerful than natural ones, and can be made of any form; they are generally used, so that the natural magnet is kept rather as a curiosity than for any purpose of real utility.

C. What are the leading properties of the magnet?

T. 1st. A magnet attracts iron. 2d. When placed so as to be at liberty to move in any direction, its north end points towards the north pole, and its south end towards the south pole: this is called the *direction* of the magnet. 3d. When the *north* end of one magnet is presented to the *south* end of another, they will attract one another. But if the two *south*, or the two *north* ends are brought together, they will repel each other. 4th. When a magnet is so situated as to be at liberty to move any way, it inclines one of its ends towards the horizon, and, of course, elevates the other end above it: this is called the *inclination* or *dipping* of the magnet. 5th. Any magnet may be made to impart its properties to iron and steel.

C. And are iron and steel the only magnetic bodies?

T. No; nickel, cobalt, and a few others, have the property of being attracted by magnets, though far less energetically; as have also such chemical compounds as contain any of these metals. All other bodies are *repelled* by magnets; these are termed *diamagnetics* by Professor Faraday, to whom the world is indebted for the discovery of this extraordinary fact, as also of many others in these sciences, and to which we shall refer as we go on.

Faraday has also shown that oxygen gas is magnetic; while all other gases are diamagnetic. And so magnetic is this gas, that an equal weight of oxygen is three times more attracted than is concentrated solution of proto-chloride of iron, which is, *however*, the most magnetic liquid known.

C. But how could he manage to handle this gas so as to magnetise it?

T. He allowed a current of this gas to descend between the poles of a very powerful electro-magnet; and found it obedient to the magnet. He also found that the denser it was, the more magnetic it was; and the colder it was, the more magnetic it was.

C. Then the atmosphere, which is mostly oxygen, is magnetic?

T. It is; and some remarkable discoveries are arising from this. It promises to explain the daily and periodical variations in the direction of the declination needle, which we shall refer to in a future conversation. For the present it will be enough for you to know that actual experiment has proved that the air is magnetic,—that its magnetic properties vary with its temperature,—and that the changes from day to night, and from winter to summer, are constantly disturbing this temperature; and with it the magnetism of the air.

CONVERSATION II.

Magnetic Attraction and Repulsion.

T. Here is a thin iron bar, eight or nine inches long, rendered magnetic, and on that account, it is now called an artificial magnet: I bring a small piece of iron within a little distance of one of the ends of the magnet, and you see it is attracted or drawn to it.

C. Will not the same effect be produced, if the iron be presented to any other part of the magnet?

T. The attraction is strongest at the poles, and it grows less and less in proportion to the distance of any part from the poles; so that, in the middle, there is no attraction, as you shall see by means of this large needle.

J. When you held the needle near the pole of the magnet, the magnet moved, which looks as if the needle attracted the magnet.

T. You are right; the attraction is mutual, as is evident from the following experiment. I place this small magnet on a piece of cork, and the needle on another piece, and let them float on water at a little distance from each other, and you observe that the magnet moves towards the iron, as much as the iron moves towards the magnet.

C. If two magnets were put in this situation, what would be the effect?

T. If poles of the same name, that is, the two north or the two south, be brought near together, they will repel one another; but if a north and a south pole be presented, the same kind of attraction will be visible as there was between the magnet and needle. In fact, the reason why a magnet attracts iron, is because it makes the iron a magnet as long as it is near it, and if a north pole is used, the near end of the iron becomes a south pole, and *therefore* is attracted. Hold this bar of soft iron in your hand, and try to suspend the small key to its lower end. You cannot: I now bring the magnet *near*, but without touching the other end, and the key is immediately attracted, just as if the soft iron were a magnet, and so it is, as long as the magnet is near; but as soon as I remove the magnet the key falls.

J. Will there be any attraction or repulsion if solid bodies, as paper or thin slips of wood, be placed between the magnets, or between the magnet and iron?

T. Yes: bring the magnets together within the attracting or repelling distance, and hold a slip of wood between them; you see they both come to the wood.

J. Is magnetic attraction and repulsion at all like what we have sometimes seen in electricity?

Fig. 1.

T. In some instances there is a certain similarity. Tie two pieces of soft iron wire each to a separate thread, which join at top, and let them hang freely from a hook. If I bring the marked or north end of a magnetic bar under them, you will see the wires repel one another, as they are shown in the figure hanging from z.

C. Is that occasioned by the repelling power which both wires have acquired in consequence of being both rendered magnetic with the same pole?

T. It is; for under the circumstances just given, the lower ends of each wire become south poles, and the upper ends north poles; and therefore, being in juxta-position, the south or lower ends repel, and the north or upper ends do so too; they therefore combine in causing the wires to separate.

J. Will they remain long in that position?

T. If the wires are of very soft iron they will quickly lose their magnetic power; but if steel wires be used, as common sewing needles, they will continue to repel each other after the removal of the magnet.

Example II. I lay a sheet of paper flat upon a table, and strew some iron filings upon it. I now lay this small magnet under the paper, and give the table a few gentle knocks, so as

Fig. 2.

to shake the filings, and you observe in what manner they have ranged themselves about the magnet.

C. At the two ends, or poles, the particles of iron form themselves into lines a little sidewise; they bend, and then form complete arches, reaching from some point in the northern half of the magnet to some other point in the southern half. Pray, how do you account for this?

T. Each of the particles of iron, by being brought within the sphere of the magnetic influence, becomes itself magnetic, and possessed of two poles, and, consequently, disposes itself in the same manner as any other magnet would do, and also attracts with its extremities the contrary poles of other particles.

J. Does the polarity of the magnet reside only in the two ends of its surface?

T. Like the centre of gravity, there is a centre or resultant of magnetic force, and this resides near the end: in a regularly formed magnet, this spot is *near*, but not at each end, and the middle has no magnetic action. But if the bar be now broken across the middle, each half will be found to be a perfect magnet with a pole at each end.

CONVERSATION III.

The Method of making Magnets — Of the Mariner's Compass.

C. How are magnets made?

T. The best method of making artificial magnets is to apply one or more powerful magnets to pieces of hard steel, taking care to apply the north pole of the magnet or magnets to that extremity of the steel which is required to be made the south pole, and to apply the south pole of the magnet to the opposite extremity of the pieces of steel.

J. Has a magnet, by communicating its properties to other bodies, its own power diminished?

T. No, it is even increased by it. A bar of iron, three or four feet long, kept some time in a vertical position, will become magnetic, the lower extremity of it attracting the south pole

and repelling the north pole. But if the bar be inverted, the polarity will be reversed.

C. Will steel produce the same effects?

T. It will not; the iron must be soft; and hence bars of soft iron that have been long in a perpendicular position are generally found to be magnetical, as fire-irons, bars of windows, &c. If a long piece of hard iron be made red hot, and then left to cool in the direction of the dipping needle, it usually becomes magnetic.

Striking an iron bar with a hammer, or rubbing it with a file, while held in this direction, renders it magnetic. An electric shock and lightning frequently render iron magnetic, by the mechanical action which they exercise over the molecules of iron while in the favorable position above mentioned.

C. But what is there peculiar in this position?

T. I have shown you that iron becomes magnetic by mere proximity to a magnet. Now, the earth acts as a magnet: and the direction of the resultant of the force is northward and downward, not exactly *beneath* our feet, but northward of it. And as upright bars of iron are not many degrees removed from this direction, they are magnetic by the earth.

J. An artificial magnet, you say, is often more powerful than the real one: can a magnet, then, communicate to steel a stronger power than it possesses?

T. Certainly not: but two or more magnets, joined together, may communicate a greater power to a piece of steel, than either of them possesses singly.

C. Then you gain power according to the number of magnets made use of?

T. Yes; very powerful magnets may be formed by first constructing several weak magnets, and then joining them together to form a compound one, and to act more powerfully upon a piece of steel.

The following are methods for forming artificial magnets:

1. Place two magnetic bars, A and B, in a line, so that the north or marked end of one shall be opposite to the south end of the other, but at such a distance that the magnet C, to be touched, may rest with its marked end on the unmarked end of B, and its unmarked end on the marked end of A. Now apply the north end of the magnet L and the south end of D to the middle of C, the opposite ends being elevated as in the figure. Draw L and D asunder along the bar C, one towards A, the other towards B,

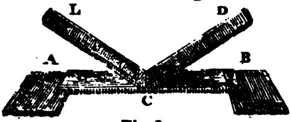


Fig. 3.

preserving the same elevation: remove L D a foot or more from the bar, when they are off the ends; then bring the north and south poles of these magnets together, and apply them again to the middle of the bar C as before: the same process is to be repeated five or six times; then turn the bar, and touch the other three sides in the same way, and, with care, the bar will acquire a strong fixed magnetism.

2. Upon a similar principle, two bars, A B, C D, may be rendered magnetic. These are supported by two bars of iron, and they are so placed that the marked end B may be opposite to the unmarked end D; then place the two attracting poles *g* I on the middle of A B, as in the figure, moving them slowly over it ten or fifteen times. The same operation is to be performed on C D, having first changed the poles of the bars, and then on the other faces of the bars; and the business is accomplished.

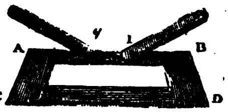


Fig. 4.

The touch thus communicated may be farther increased by rubbing the different faces of the bars with sets of magnetic bars, disposed as in this diagram.

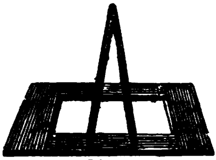


Fig. 5.

J. I suppose all the bars should be very smooth.

T. Yes; they should be well polished, the sides and ends made flat, and the angles quite square, or right angles.

There are many magnets made in the shape of horseshoes; these are called horseshoe magnets; and they retain their power very long, if care be taken to join a piece of iron to the end when they are not in use.

C. Does that prevent its power from escaping?

T. It should seem so; the power of a magnet is even increased by suffering a piece of iron to remain attached to one or both of its poles. Of course a single magnet should always be thus left.

J. How is magnetism communicated to compass needles?

T. Fasten the needle down on a board, and draw magnets about six inches long, in each hand, from the centre of the needle outwards; then raise the bars to a considerable distance from the needle, and bring them perpendicularly down on its centre, and draw them over again, and repeat this operation about twenty times, and the needle will acquire directive properties.

By a little management, steel may be magnetised without any

other source of magnetism than that derived from the earth. A bar of soft steel is tied to a common iron poker, held upright, and it is then rubbed from its lower end upwards with the tongues; other similar bars undergo the same treatment. They are then bundled together; two harder steel bars are placed, as in fig. 4., connected with soft iron, into a parallelogram; these are rubbed with the magnetised bars; other hard steel bars are rubbed in the same way until six are prepared; the softer steel are now placed aside, and the rubbing of two of the hard steel is effected by four of the hard steel; and thus, by a succession of operations, a powerful set of magnets may be obtained.

Dr. Scoresby has taken great pains in studying the best methods of preparing magnets; for minute particulars I must refer you to his book, where you will see the relative values of different kinds of steel for different kinds of magnets.

C. What are the characters of a good magnet?

T. Capacity, or power of receiving a good amount of magnetism, and *tenacity*, or power of retaining it; the latter is a most important property; and he has found that hardness and tenacity are related. He has also described a mode by which, as he says, "he would have no difficulty in constructing a magnet of a ton weight." He magnetises a large quantity of small bars of steel, and these he bundles together in proper order; and although each one loses a certain quantity of force, on account of its proximity to the rest, yet the whole has a far greater power remaining in it than could by any means be conferred upon a solid mass of steel.

J. But have I not long ago seen this plan in the compound horseshoe magnet?

T. No; in all the old plans the individual bars were of the same length as the compound mass; but in this plan many shorter bars are used, and they are joined by being placed end to end.

C. I remember seeing a compass, when I was on board the frigate that lay off Worthing: the needle was in a box, with a glass over it.

T. The mariner's compass consists of the box, the card or fly, and the needle. The box is circular, and is so suspended as to retain its horizontal position in all the motions of the ship. The glass is intended to prevent any motion of the card by the wind; the card or fly moves with the needle, which is very nicely balanced on a centre. It may, however, be noticed, that a needle, which is accurately balanced before it is magnetised, will lose its balance by being magnetised, on account

of what is called the *dipping*, therefore a small weight, or moveable piece of brass, is placed on one side of the needle, by the shifting of which the needle will always be balanced.

It must be observed that, in the construction of such instruments, neither iron, steel, or other ferruginous matter, must be suffered to be in, or even near, the frame, because a very small quantity of it is sufficient to render the observations of no value whatever. And, indeed, it has been ascertained lately, that the masses of iron on board ship have all a tendency to draw the needle from its true direction. Mr. Barlow, of the Royal Military Academy, has discovered a method of ascertaining, and allowing for, the magnitude of the deviation thus occasioned in any particular ship. Such a discovery cannot but prove highly valuable to mariners; and, indeed, has been found so by Sir J. Parry, Sir J. Franklin, and many of our most skilful naval officers.

The principle on which he acted was first to discover the effect of the ship on the needle, and then to provide a disc of iron that should have the *same* amount of action: so that, when he removed the iron from near the needle, whatever difference was lost was just half of the whole action of the ship.

CONVERSATION IV.

Of the Variation of the Compass.

C. You said, I think, that the magnet pointed *nearly* north and south: how much does it differ from that line?

T. It rarely points exactly north and south, and the *deviation* from that line is called the *declination of the needle*, which is said to be east or west.

J. Does this differ at different times?

T. It does; and is very different in different parts of the world. It is not the same now that it was half a century ago, nor is it the same now at London that it is in Bengal or Kamschatka. The needle is continually traversing slowly towards the east or the west. It seems, however, now to have attained its western limit at London, and is going back again.

This subject was first attended to by Mr. Burrows, about the year 1580, and he found the declination then at London, about 11° 11′ east. In the year 1657, the needle pointed due north and south: since which the declination has been gradually increasing towards the west; and in the year 1803 it was equal to something more than 24° west, and was then advancing towards the same quarter.

C. That seems to have been at the rate of something more than ten minutes each year.

T. It is; but the annual variation is not regular. It is more one year than another. It is different in the several months, and even in the hours of the day. The mean declination in January, 1853, was 22° 15′ west at Greenwich.

J. Then if I want to set a globe due north and south, to point out the stars by, I must move it about, till the needle in the compass points to 22° 15′ west?

T. Just so; and mariners knowing the declination at different places are as well able to sail by the compass, as if it pointed due north.

C. You mentioned the property which the needle had of *dipping*, after the magnetic fluid was communicated to it: is that always the same?

T. No; it also varies slightly. It was discovered by Robert Norman, a compass-maker, in the year 1576, and he then found it to dip nearly 72°. The dip in January, 1853, from the observations made at the Royal Observatory, Greenwich, was 68° 40′.

J. Does it differ in different places?

T. Yes: in the year 1773, observations were made on the subject, in a voyage towards the north pole; and from these it appears that

In latitude 60°	18′	the dip was	75°	0′
. 70	45	. . . . .	77	52
. 80	12	. . . . .	81	52
. 80	27	. . . . .	82	2½

The dip always being greater as the distance from the *magnetic equator* is greater.

C. What is the magnetic equator?

T. It girdles the earth within the torrid zone; it cuts the terrestrial equator in longitude 10° east and longitude 170° east; it reaches about as far north as 10°, and as far south as 18°: it is a sinuous and very irregular curve. There is no dip or, as it is better called, *inclination* of the needle along the line of this equator.

C. And I suppose there are magnetic poles also?

T. Yes; and they are as peculiar in their irregularity as the equator. The north magnetic pole is near Hudson's Bay, in 70° 5′ 17″ of latitude, and 114° 55′ 18″ west longitude. The southern magnetic pole is supposed to be in 72° 35′ of latitude, and 152° 30′ of east longitnde. The dipping needle hangs vertically at these places, the inclination being therefore 90°.

Magnetic meridians are curved lines terminating at the mag-

netic poles, and cutting the magnetic equator: they are drawn through the places where the declinations are similar.

The lines of *equal inclination* are drawn in a direction somewhat parallel to the magnetic equator, and pass through the places where the dip or inclination is the same.

C. Can you show me any experiment in illustration of the dip of the needle?

T. Here is a magnetized bar and a small dipping needle: if I carry the needle, suspended freely on a pivot, from one end of the magnetized bar to the other, it will, when directly over the south pole, settle directly perpendicular to it, the north end being next to the south pole. As the needle is moved, the dip grows less and less, and when it comes to the magnetic centre, it will be parallel to the bar; afterwards the south end of the needle will dip, and when it comes directly over the north pole, it will be again perpendicular to the bar.

C. You promised to tell us of the relation between atmospheric temperature and magnetic variations.

T. Independently of the changes which in the course of years have carried the magnetic pole to the west of the true north, and are now restoring it slowly to a true north direction in respect to London, and at the rate of a very few minutes of a degree in each year, there are daily changes, which vary in amount with the place and the season, and which are evidently connected with solar heat. These are greater in the summer months than in the winter, and attain a maximum from noon for an hour or two and then recede.

The *intensity*, — that is, the magnetism of the earth itself, — as shown by the magnet, also varies in amount, and unquestionably from like causes.

Before we quit the subject of magnetism, I will present you with a summary of facts and principles, which may be found useful in your future researches:

1. Iron bars become magnetical by position, except when they are placed in the plane of the magnetic equator, — that is, in a plane which is perpendicular to the direction of the dipping needle.

2. Before a magnet can attract iron that is totally free from both permanent magnetism and that of position, it infuses into the iron a magnetism of contrary polarity to that of the attracting pole.

3. An iron bar, with permanent polarity, when placed anywhere in the plane of the magnetic equator, may be deprived of its magnetism by a blow.

4. Iron heated to redness, and quenched in water, in a vertical

position, becomes magnetic, the upper end gaining south polarity, and the lower end north.

5. Hot iron receives more magnetism of position than the same when cold.

6. Magnetic attraction follows the same law as that of gravitation; being inversely as the square of the distance.

7. The plane of the magnetic equator is a plane of no attraction.

8. Magnetic attraction does not depend upon the mass, but upon the surface; a shell of iron attracts a magnet equally with a ball of the same diameter.

9. An electric discharge, made to pass through a bar of iron void of magnetism, when nearly in the position of the magnetic axis (i. e. of the *dipping needle*), renders the bar magnetic; the upper end becoming a south pole, and the lower a north pole: but the discharge does not produce any polarity, if the iron be placed in the plane of the magnetic equator.

10. A bar of iron, possessing some magnetism, has its polarity diminished, destroyed, or inverted, if an electric discharge be passed through it, when it is nearly in the position of the magnetic axis, provided the south pole of the bar be downward; while its magnetism is weakened or destroyed, if it receive the shock when in the plane of the magnetic equator.

11. Iron is rendered magnetical, if a stream of the electric fluid be passed through it, when it is in a position nearly corresponding with that of the magnetic axis; but no effect is produced when the iron is in the plane of the magnetic equator.

CONVERSATION V.

On Diamagnetics, and on the Magnetization of Light. Magneto-Crystalline Action.

J. You mentioned *diamagnetics* in connection with the name of Dr. Faraday: I am sure there is something instructive in this as in all the labours of that industrious philosopher.

T. Yes, indeed there is; I have heretofore been talking of iron and steel, and a few other bodies, which place themselves in a certain direction with reference to the magnet; now all other bodies take a direction exactly at right angles to this. As, for instance, if I suspend a needle freely above the two poles of a horseshoe magnet, it will place itself in a direction from pole to pole, whereas, if it were a slip of wood, a piece of apple, or a candle-end &c. it would place itself across this direction.

C. This is curious: I must run and fetch my magnet, in order to see it act upon a piece of apple.

T. It will be of no use, my boy: for this can only be accomplished by the use of exceedingly powerful magnets; and these are obtained by a process that I will describe hereafter. In the course of his investigations, Dr. Faraday has found that the magnetic bodies are iron, nickel, cobalt, manganese, chromium, cerium, titanium, palladium, platinum, and osmium; and that all other bodies constitute the new class that he has termed *diamagnetics*. The following, according to the order in which they stand, exhibit it: bismuth (which is the most powerful, and is the type of the class), phosphorus, antimony, zinc, lead, tin, flint-glass, mercury, water, gold, alcohol, and ether. On investigating the subject more closely, he found, by using one pole of a magnet, that, as magnetic bodies are *attracted*, diamagnetic bodies are actually *repelled* by a magnet. Or, as he expressed it more generally, that, in the *field of magnetic force*,—viz. in the space where the effects of a magnet are felt,—*magnetic* bodies go from weaker to stronger places; and *diamagnetic* from stronger to weaker.

But there are no such things as diamagnetic poles and polarity, which shows that the force is essentially different from what we have so long known under the name of magnetism. He has also proved that not only is iron magnetic, but all other compound bodies into which iron enters are also magnetic.

He has also completed another series of researches, to which I will briefly refer you, in which he has shown the action of magnetism upon light. He allows a ray of polarised light to pass through certain transparent bodies; heavy glass, made of borate of lead, is the best for this purpose: he then turns the analysing plate until the ray is at its minimum of intensity, or nearly extinguished; a very powerful magnet is now made to act upon the glass, and the ray is immediately illuminated; in fact, the same effect is produced as if the analysing plate had been turned back. If, on the other hand, the ray had been first brought to its maximum of intensity, and the magnet had then been introduced, the ray is immediately extinguished. You will remember, that when I described the circular rotation of polarised light by the application of various media, it was right-handed or left-handed to the observer, as the case might be, whichever way he looked into the medium; but here, it is right-handed by looking into one end, and it is left-handed by looking into the other.

J. Is the ray of polarised light to pass in the direction of the line that joins the magnetic poles, or at right angles to this line?

T. In the line that joins the poles; and, if the poles are so placed that the north pole is nearer to the observer, and the south more distant, the rotation occurs from left to right, and *vice versâ.* The angles of magnetic rotation vary with the thickness of the body through which the ray of light passes, and are different in different bodies; as, for instance,

Faraday's heavy glass - - - -	1·00
Sulphuret of carbon - - - -	·74
Water - - - - - - - -	·25
Ether - - - - - - -	·15

J. Since magnetic rotation of the ray depends on the relative position of the magnetic poles, I presume it is quite independent of natural circular rotation, as described to us in the conversations upon light.

T. It is; and according as the two phenomena are in the same, or in contrary directions, the resulting effect is either the *sum* or the *difference* of the two. M. E. Becquerel passed a polarised ray at the same time through a piece of Faraday's heavy glass, which gave a rotation of 16°, and through a column of syrup made of just the length to produce the same deviation, and he obtained either 32° or 0°, according as he exposed the glass to magnetism in a favourable or in a converse direction.

C. Does the magnetism act on the ray of polarised light itself, or on the particles of the transparent body?

T. It does not act directly on the ray; for polarised light passing through vacuum is unaffected; and, as it does not vary the relative position of the particles, it acts by their intervention in a manner that is not clearly understood. De la Rive has pointed out, that there is a manifest relation between the magnetic rotation and the refracting power of bodies, and he says, that these new phenomena that have been discovered by Faraday, "ought to be attributed to an action of magnets and electric currents, exercised neither on the particles alone, nor on the ether alone, but on the manner of the existence of the particles in respect to the ether."

I have not troubled you with the phenomena of the polarisation of heat, which is accomplished by a piece of rock-salt; but I may, in passing, tell you that a polarised ray of heat is also made to rotate by means of magnetism.

C. Then there is, at any rate, a strong relation between light and magnetism.

T. There is, as we have seen, a very marked relation. Faraday also discovered what he calls a *magneto crystalline* force.

C. I suppose this means that magnets act upon crystals?

T. Yes; and the relations depend on the direction of the crystalline axis. For isntance, an ordinary mass of bismuth places itself, with respect to a magnet, across the line that joins the magnetic poles; but a crystal of bismuth places itself so that the line, or great axis of the crystal, is directed from pole to pole; and this, whether the said axis be in the longer or shorter length of the piece under examination.

C. And are crystalline compounds of metals affected by this force?

T. Sulphate of iron is a magnetic body; but a regular crystal of this salt directs itself quite independently of its magnetic properties. A crystal of cyanite, when delicately suspended, has been actually found to be influenced by terrestrial magnetism, and to take a determinate direction, according to the position of the *magne-crystalline line.* A crystal of oxide of tin is the most powerfully directed by terrestrial magnetism; and it even acts upon a magnetised needle. Faraday found that a bismuth crystal, by using proper precautions, took a true direction in regard to the poles of the earth.

C. Is a magnetic body, which should essentially be *attracted* by a magnet, made by the magneto-crystalline force to resemble a diamagnetic body, and be *repelled?*

T. No; and this is the distinctive character of this force. It is neither attractive nor repulsive, but simply *directive.* The other forces act on the whole mass; this force acts on the optic axis alone, and is dependent upon the molecular arrangement of the particles of the crystal itself, which are nearer to each other in one direction, than they are in the others. And it is very immaterial which *end* of the optic axis is in any given direction. Of its ends A B, A may be presented to the north pole, and B to the south or *vice versâ.*

C. I scarcely understand your expression "molecular arrangement?"

T. You may understand this from the following experiment:—If, from a piece of gutta percha that is made fibrous by the manufacturer, two slips are taken, one with the fibres lengthwise, and the other with the fibres crosswise, the former will take the direction of a magnetic body, and the latter the direction of a diamagnetic body. The only difference in the two cases being in the structural arrangement; and this is the case with true crystals.

You know that crystals split in one direction better than in another. This is called the direction of the *planes of cleavage.* And magneto-crystalline action is such that, in crystals of magnetic bodies, the planes of cleavage take the direction of a

magnetic body, viz. from pole to pole, called by Faraday the *axial* direction; while crystals of diamagnetic bodies take the direction of a diamagnetic body, viz. at right angles to the line joining the poles, which has been termed the *equatorial* direction.

The direction assumed has been termed the *line of elective polarity*, and is affected by whatever affects the molecular structure; and disappears when this structure disappears, as when bismuth or antimony crystals are heated to the point of fusion.

ELECTRICITY.

CONVERSATION I.

INTRODUCTION.

Tutor — Charles — James.

The Early History of Electricity.

T. If I rub pretty briskly this stick of sealing-wax, and then hold it near any light substances, as little pieces of paper, they will be attracted, and will jump up and adhere to the wax.

C. They do; and I think I have heard you call this the effect of electricity: but I do not know what electricity is.

T. It is the case with this part of science as with many others — we know it only by the effects, which it produces. As I have not hitherto, in these Conversations, attempted to bewilder your minds with too much theory, neither shall I, in the present case, attempt to say what electricity is: its action is well known; it seems diffused over every portion of matter, and by the use of proper methods, is as easily collected.

J. I see nothing adhering to the sealing-wax, when you have rubbed it.

T. You do not see the air with which you are surrounded, yet I have shown you* that it may be taken from any vessel, as certainly as water may be poured from this glass. With the exercise of a small degree of patience, you shall see such experiments as will not fail to convince you that there is a something, or a power added to the wax by rubbing it.

C. But who discovered electricity, which is not at all evident to the sense either of sight or feeling?

T. Thales, who lived six centuries before the Christian era, was the first who observed the electrical properties of amber, and he was so struck with the appearances that he supposed it to be animated.

J. Does amber, like sealing wax, attract light bodies?

T. Yes, it does; and there are many other substances as well

* See Hydrostatics and Pneumatics.

as these that have the same power. After Thales, the first person we read of that noticed this subject was Theophrastus, who discovered that *tourmalin* has the power of attracting light bodies. It does not, however, appear that the subject, though very curious, excited much attention till about 200 years ago, when Dr. Gilbert, an English physician, examined a great variety of substances, with the view of ascertaining how far they might or might not be ranked among *electrics*.

C. What is meant by an *electric*?

T. Any substance which, being excited or rubbed by the hand, or by a woollen cloth, or other means, has the power of attracting light bodies, is called an *electric*.

J. Is not electricity accompanied with a peculiar kind of light, and with sparks?

T. It is; of which we shall speak more at large hereafter. The celebrated Mr. Boyle is supposed to have been one of the first persons who got a glimpse of the electrical light, or who seems to have noticed it, by rubbing a diamond in the dark. But he little imagined at that time what astonishing effects would be afterwards produced by the same power. Sir Isaac Newton was the first who observed that excited glass attracted light bodies on the side opposite to that on which it was rubbed.

C. How did he make the discovery?

T. Having laid upon the table a round piece of glass, about two inches broad, in a brass ring, by which it was raised from the table about the eighth of an inch, and then rubbing the glass, some little bits of paper which were under it were attracted by it, and moved very nimbly to and from the glass.

C. I remember standing by a glazier when he was rubbing over some window-lights with oil, and cleaning it off with a stiff brush and whiting, and the little pieces of whiting under the glass kept continually leaping up and down, as the brush moved over the glass.

T. That was, undoubtedly, an electrical appearance of the same kind, but I do not remember having ever seen it noticed by any writer on electricity. To-morrow we shall enter into the practical part of the subject; and I doubt not that the experiments in this part of the science will be as interesting as those in any other which you have been studying. The electric light, exhibited in different forms; the various signs of attraction and repulsion acting on all bodies; the electric shock, and the explosion of the battery, will give you pleasure and excite your admiration.

CONVERSATION II.

Of Electric Attraction and Repulsion. — Of Electrics and Conductors.

T. You must, for a little time, that is, till we exhibit before you experiments to prove it, regard the earth and all bodies upon it as a great magazine of electricity. A certain quantity belongs to all bodies, and this is called their natural quantity; and so long as a body contains neither more nor less than this quantity, no sensible effect is produced.

J. Has this table electricity in it?

T. Yes, and so has everything else in the room; and if I were to take proper means to put more into it than it now out and you were to put your knuckle to it, it would throw it has, in the shape of sparks.

J. I should like to see this done.

C. But what would happen if you should take away some of its natural quantity?

T. Why, then, if you presented any part of your body to the table, as your knuckle, a spark would go from you to the table.

J. But perhaps Charles might not have more than his natural share, and, in that case, he could not spare any.

T. True; but to provide for this, the earth on which he stands would lend him a little, to make up for what he parted with to the table.

J. This must be an amusing study; I think I shall like it better than any of the others.

T. Take care you do not pay for the amusement before we have done.

Here is a glass tube about eighteen inches long, and perhaps an inch or more in diameter. I rub it up and down quickly in my hand, which is dry and warm, and now I will present it to these fragments of paper, thread, and gold-leaf. You see they all move to it. That is called electrical *attraction.*

C. They jump back again now; and now they return to the glass.

T. They are, in fact, alternately attracted and repelled, and this will last several minutes, if the glass be strongly excited. I will rub it again; present your knuckle to it in several parts, one after another.

J. What is that snapping? I feel, likewise, something like the pricking of a pin.

T. The snapping is occasioned by little sparks which come

from the tube to your knuckle, and these give the sensation of pain.

Let us go into a dark room, and repeat the experiment.

C. The sparks are evident enough now; but I do not know where they can come from.

T. The air and everything is full of electricity; and, whatever be the cause, which I do not attempt to explain, the rubbing of the glass with the hand collects it, and having now more than its natural share, it parts with it to you, or to me, or to anybody else that may be near enough to receive it.

J. Will any other substance besides the hand excite the tube?

T. Yes, many others, and these, in this science, are called the *rubbers*; and the glass tube, or whatever is capable of being thus excited, is called an *electric*.

C. Are not all sorts of solid substances capable of being excited?

T. You may rub this poker, or the round ruler, for ever, without obtaining an electric spark from it.

J. But you said one might get a spark from the mahogany table, if it had more than its share.

T. So I say you may have sparks from the poker or ruler, if they possess more than their common share of electric fluid.

C. These bodies appear to be divided into two classes?

T. Yes; and these from their general characters are termed *conductors* and *non-conductors*. The metals are the best conductors; resin and shell-lac are the worst. There is a gradually descending scale, so that the two classes merge into each other; so that, in fact, a non-conductor is nothing more than a bad conductor, though still *a* conductor; and a conductor is a bad insulator, but still an insulator.

C. I can scarcely understand this.

T. Each of the bodies holds its rank as a conductor or a non-conductor only by comparison; copper, for instance, is a very good conductor, and air a very bad one; yet if an electric discharge is about to take place, and there be two paths opened out to it, one of great length through copper wire, and the other of a small interval of air, the greater portion of the charge will pass by the latter path.

J. I heard you make use of the word *insulator*. I suppose it is synonymous with non-conductor.

T. It is; and it is by the knowledge of which are the best insulators that we are enabled to conduct our experiments; for unless we select means of preventing an escape of electricity, it is in vain to accumulate it. Silk, if dry, is a non-conductor. With this skein of sewing silk I hang the poker A to a hook in

the ceiling, so as to be about twelve inches from it; underneath, and near the extremity, are some small substances, as bits of paper, &c. I will excite the glass tube, and present it to the upper part of the poker.

C. They are all attracted; but now you take away the glass, they are all quiet.

T. It is evident that the electricity passed from one part of the tube through the poker, which is a conductor to the paper, and attracted it. If the glass be properly excited you may take sparks from the poker.

J. Would not the same happen if another glass tube were placed instead of the poker?

T. You shall try. Now I have put the glass in the place of the poker, but let me excite the other tube as much as I will, no effect can be produced on the paper: there are no signs of electrical attraction, which shows that the electricity will not pass through glass.

Fig. 1.

C. What would have happened if any conducting substance had been used instead of silk to suspend the iron poker?

T. If I had suspended the poker with a moistened hempen string, the electricity would have all passed away through that, and there would have been no (or very trifling) appearance of electricity at the end of the poker. Sealing-wax may be excited as well as a glass tube, and will produce similar effects.

The following is a list of bodies in the order of their conducting powers, beginning with the best conductor, and ending with the worst conductor or best insulator. I have drawn a line between the last of what are in general terms called conductors, and the first in the list of insulators.

All the metals.	Smoke.
Carbon.	Soluble salts.
Plumbago.	Earths and moist rocks.
Acids.	Powdered glass.
Saline solutions.	Flowers of sulphur.
Metallic ores.	———
Sea-water.	Dry oxides.
Spring-water.	Oils.
Rain-water.	Vegetable ashes.
Ice above 13° Fahr.	Animal ashes.
Flame.	Dry crystals.

Ice below 13° Fahr.
Phosphorus.
Lime.
Dry chalk.
Caoutchouc.
Camphor.
Marble.
Porcelain.
Baked wood.
Dry air.
Leather.
Parchment.
Dry paper.
Feathers.
Hair. Wool.
Silk.
Precious stones.
Diamond.
Vitrefactions.
Glass.
Jet.
Wax.
Sulphur.
Resins.
Gutta percha (?)
Amber.
Gum-lac.

CONVERSATION III.

Of the Electrical Machine.

T. I will now explain to you the construction of the electrical machine, and show you how to use it.

C. For what purpose is it used?

T. Soon after this subject engaged the attention of men of science, they began to contrive the readiest methods of collecting large quantities of electricity. By rubbing this stick of sealing-wax I can collect a small portion: if I excite or rub the glass tube, I get still more. The object, therefore, was to find out a machine by which the largest quantities can be collected, with as little trouble and expense as may be.

J. You get more electricity from the tube than from the sealing-wax, because it is five or six times as large: by increasing the size of the tube, you would increase the quantity, I should think.

T. That is a natural conclusion; and on this principle the electrical machines have been constructed.

A common form is a glass cylinder, from five or six inches in diameter, to ten or twelve. Here is one completely fitted up. The cylinder A B is about eight inches in diameter, and twelve or fourteen in length; this I turn round in the framework, with *the handle* D C.

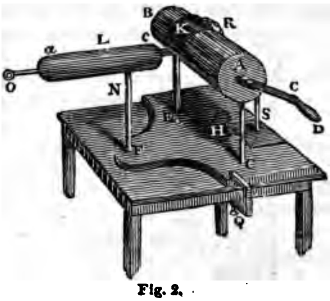


Fig. 2.

J. What is the piece of black silk K for?

T. The cylinder would be of no use without a rubber, you know; on which account you see the glass pillar R S, which, being cemented into a piece of hard wood, is made to screw into the bottom of the machine; on the pillar is a cushion, to which is attached a piece of black silk.

C. And I perceive the cushion is made to press hard against the glass.

T. This pressure, when the cylinder is turned round fast, acts precisely like the rubbing of the tube by the hand, though in a still more perfect manner. I will turn it round.

J. There is not much sign of electricity yet.

T. No: the machine is complete, but it has no means of collecting the fluid from the surrounding bodies: for you see the cushion or rubber is fixed on a glass pillar, and glass will not conduct electricity.

C. Nevertheless, it does, by turning round, show some signs of attraction.

T. The signs, which are now evident, arise from the small quantity which exists in the rubber itself, and the atmosphere, that immediately surrounds the machine.

C. Would the case be different if the rubber were fixed on a conducting substance instead of glass?

T. It would; but there is a much easier method: I will hang this brass chain to the cushion at R, which, being several feet long, lies on the table or on the floor, and this you know is connected, by means of other objects, with the earth, which is the grand reservoir of electricity. Now see the effect of turning round the cylinder; but I must make every part of it dry and rather warm, by rubbing it with a dry warm cloth.

J. It is indeed very powerful. What a crackling noise it makes!

T. Shut the window-shutters.

C. The appearance is very beautiful: the flashes from the silk dart all round the cylinder.

T. I will now bring to the cylinder the tin conductor L, which is also placed on a glass pillar, F N, fixed in the stand at F.

J. What are the points in the tin conductor for?

T. They are intended to collect the electricity from the cylinder. I will turn the cylinder, and do you hold your knuckles within four or five inches of the conductor.

C. The painful sensations which the sparks occasion, prove that electricity is a very powerful agent when collected in large quantities.

T. To show you the nature of conducting bodies, I will now

throw another brass chain over the conductor, so that one end of it may lie on the floor. See now if you can get any sparks while I turn the machine.

J. No, I can get none, put my knuckle as near to it as I will. Does it all run away by the chain?

T. It does; a piece of brass or iron wire would do as well; and so would any conducting substance which touched the conductor with one end, and the floor with the other: your body would do as well as the chain. Place your hand on the conductor, while I turn round the cylinder; and let your brother bring his knuckle near the conductor.

C. I can get no spark.

T. It runs through James to the earth, and you see his body is a conductor as well as the chain. With a very little contrivance I can take sparks from you or James, as well as you did from the conductor.

J. I should like to see how that is done.

T. Here is a small stool, having a mahogany top and glass legs. If you stand on that, and put your hand on the conductor, the electricity will pass from the conductor to your body.

C. Will the glass legs prevent its running from him to the earth?

T. They will; and, therefore, what he receives from the conductor, he will be ready to part with to any of the surrounding bodies, or to you, if you bring your hand near enough to any part of him.

J. The sparks are more painful in coming through my clothes than when I received them on my bare hand.

T. They are: you understand, I hope, the process.

C. By means of the chain trailing on the ground, the electricity is collected from the earth on the glass cylinder, which gives it by means of the points to the conductor; from this it may be conveyed away again by means of other conductors.

T. Whatever body is supported, or prevented from touching the earth or communicating with it, by means of glass, or other non-conducting substances, is said to be *insulated*. Thus, a body suspended on a silk line is insulated; and so is any substance that stands on glass, or resin, or wax, provided that these are in a dry state, for moisture will conduct away the electricity from any charged body.

Hence you will understand the construction of electrical machines, which are so formed as, by excitation, to collect electricity, which cannot escape again, owing to the glass cylinder, *globe, or plate* being insulated.

CONVERSATION IV.

Of the Electrical Machine.

C. What is that shining substance which I saw you put to the rubber yesterday?

T. It is called *amalgam;* the rubber, by itself, would produce but a slight excitation: its power, however, is greatly increased by laying upon it a little of this amalgam, which is made of quicksilver, zinc, and tinfoil, with a little tallow or mutton-suet; or else a little deuto-sulphuret of tin (mosaic gold).

J. Is there any art required in using this amalgam?

T. When the rubber and silk flap are very clean and dry, and in their place, spread a little of the amalgam upon a piece of leather, and apply it to the upper part of the glass cylinder while it is revolving from you; by this means, particles of the amalgam will be carried by the glass itself to the lower part of the rubber, and will increase the excitation.

C. I think I once saw a globe, instead of a cylinder, for an electrical machine.

T. You might: globes were used before cylinders, but the latter are the more convenient of the two. The most powerful electrical machines are fitted with flat plates of glass. Some of these are very powerful.

C. Yes: I have often seen the large one at the Polytechnic; the plate is seven feet in diameter; the snapping of the sparks is almost alarming, and they are ten or twelve inches in length.

J. As I was able to conduct the electricity from the conductor to the ground, could I likewise act the part of the chain, by conducting the fluid from the earth to the cushion?

T. Undoubtedly; I will take off the chain, and now do you keep your hand on the cushion while I turn the handle.

J. I see the machine works as well as when the chain was on the ground.

T. Keep your present position, but stand on the stool with glass legs; by which means there is now all communication cut off between the cushion and the earth; in other words, the cushion is completely insulated, and can only take from you what electricity it can get from your body. Go, Charles, and shake hands with your brother.

C. It does not appear that the machine had taken all the electricity from him, for he gave me a smart spark.

T. You are mistaken; he gave you nothing, but he took a spark from you.

C. I stood on the ground; I was not electrified: how then could I give him a spark?

T. The machine had taken from James the electricity that was in his body, and by standing on the stool, that is, by being insulated, he had no means of receiving any more from the earth, or any surrounding objects: the moment, therefore, you brought your hand near him, the electricity passed from you to him.

C. I certainly felt the spark; but whether it went out of, or entered into, my hand, I cannot tell: have I then less than my share now?

T. No; what you gave to your brother was supplied immediately from the earth. Here is another glass-legged stool; do you stand on this, but at the distance of a foot or two from your brother, who still keeps his place. I take the electricity from him by turning the machine, and, as he stands on the stool, he has now less than his share. But you have your natural share, because, though you also are insulated, yet you are out of the influence of the machine: extend, therefore, your hand, and give him a part of the electric fluid that is in you.

C. I have given him a spark.

T. And being yourself insulated, you have now less than your natural quantity, to supply which, you shall have some from me; give me your hand. You draw it back without my touching it!

C. I did, but it was near enough to get a strong spark from you.

T. When a person has *less* electricity than his natural share, he is said to be electrified *minus*, or negatively; but if he has *more* than his natural share, he is said to be electrified *plus*, or positively. But these terms must be used with great caution; because, after all, we are not quite sure which really is the state of having more, and which the state of having less, or whether there are such states at all: for it is more than probable, that electricity is a *force* and not a *thing*. But we must not wander into this devious path. We will use the term; but with the understanding that what we call plus or positive electricity, is that produced *on* glass when it is rubbed with silk, and what we call minus or negative, is that produced *on* sealing-wax under similar circumstances.

C. Why do you lay such a stress upon the word *on*?

T. Because the rubber as well as the body rubbed became *both* electrified, and they assume the opposite states. So that when glass is made positive by a silk rubber, the rubber itself becomes negative.

J. Then, before Charles gave me the spark, I was electrified minus; and when he had given it to me, he was minus till he received it from you.

T. That is right. Suppose you stand on a stool and hold the rubber, and Charles stand on another stool, and touch the prime conductor L, while I turn the machine, which of you will be plus, and which minus electrified?

J. I shall be minus, because I give to the rubber: and Charles will be plus, because he receives from the conductor what I gave to the rubber, and which is carried by the cylinder to the conductor.

T. You then have less than your share, and your brother has more than he ought to have. Now, if I get another glass-legged stool, I can take from Charles what he has too much, and give it to you, who have too little.

C. Is it necessary that you should be insulated for this purpose?

T. By being insulated, I may, perhaps, carry back to James the very electricity which passed from him to you. But, if I stand on the ground, the quantity which I take from you will pass into the earth, because I cannot, unless I am insulated, retain more than my natural share.

J. And what is given by you to me is likewise instantaneously supplied by the earth?

T. It is. Let us make another experiment to show that the electric fluid is taken from the earth. Here are some little balls made of the pith of elder: they are put on the thread C D, and being very light, are well adapted to our purpose.

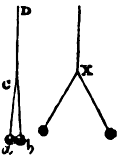


Fig. 3.

While the chain is on the cushion, and I work the machine, do you bring the balls near the conductor, by holding the thread at D.

J. They are attracted by it; and now the two balls repel each other, as in the figure X.

T. I ought to have told you that the upper part D of the line is silk, by which means you know the balls are insulated, as silk is a non-conductor. I take the chain off from the cushion and put it on the conductor, so as to hang on the ground, while I turn the machine. Will the balls be affected now, if you hold them to the conductor?

J. No, they are not.

T. Take them to the cushion.

C. They are attracted and repelled now, by being brought near the cushion, as they were before by being carried to the conductor.

T. Yes, and you may take sparks from the cushion as you did just now from the conductor: in both cases it must be evident that the electric fluid is brought from the earth.

Some machines are furnished with two *conductors*, one of which is connected with the cushion, the other such as we have described. Turn the cylinder, and both conductors will be electrified: but any body which is brought within the influence of these will be attracted by one of the conductors, and repelled by the other; and if a chain or wire be made to connect the two together, neither will exhibit any electric appearances: they seem, therefore, to be in opposite states; accordingly, electricians say that the conductor connected with the cushion is negatively electrified, and the other is positively electrified.

CONVERSATION V.

Of Electrical Attraction and Repulsion.

J. What is this large roll of sealing-wax for?

T. As I mean to explain, this morning, the principles of electrical attraction and repulsion, I have, besides the electrical machine, brought out for use a roll of sealing-wax, which is about fifteen inches long, and an inch and a quarter in diameter; I have also here the glass tube.

C. Are they not both electrics, and capable of being excited?

T. They are; but the electricity produced by exciting them has different or contrary properties. I will excite the glass tube, and Charles shall excite the wax. Now do you bring the pith balls, which are suspended on silk to the tube. They are suddenly drawn to it, and now they are repelled from one another, and likewise from the tube, for you cannot easily make them touch it again: — but take them to the excited wax.

J. The wax attracts them very powerfully: now they fall together again, and appear in the same state as they were in before they were brought to the excited tube.

T. Repeat the experiment again and again, because on this two different theories have been formed; one of which is, that there are two electricities, called, by some philosophers, the *vitreous* or positive electricity, and *resinous* or negative electricity.

C. Why are they called *vitreous* and *resinous*?

T. The word *vitreous* is Latin, and signifies any *glassy* substance; and the word *resinous*, used to denote that the electricity produced by resins, wax, &c., possesses different qualities *from that* produced by glass.

J. Is it not natural to suppose that there are two electricities, since the excited wax attracts the very same bodies that the excited glass repels?

T. It may be as easily explained, by supposing that every body, in its natural state, possesses a certain quantity of the electricity, and if a part of it be taken away, it endeavours to get it from other bodies; or, if more be thrown upon it than its natural quantity, it yields it readily to other bodies that come within its influence.

C. I do not understand this.

T. If I excite this glass tube, the electricity which it exhibits is supposed to come from my hand; but if I excite the roll of wax in the same way, the effect is, according to this theory, that a part of the electric fluid naturally belonging to the wax passes from it through my hand to the earth; and the wax, being surrounded with the air, which, in its dry state, is a non-conductor, remains exhausted, and is ready to take sparks from any body that may be presented to it.

J. Can you distinguish that the sparks came from the glass to the hand; and on the contrary, from the hand to the wax?

T. No: the velocity with which the electric spark moves renders it impossible to say what course it takes; but I shall show you other experiments which seem to justify this theory: and, as Nature always works by the simplest means, it seems more consistent with her usual operations that there should be one fluid rather than two, provided that known facts can be equally well accounted for by one as by two.

C. Can you account for all the leading facts by either theory?

T. Yes, we can. You saw when the pith balls were electrified they repelled one another. It is a general principle in electricity, that two bodies similarly electrified repel one another. But if dissimilarly, they will attract one another.

J. How is this shown?

T. I will hold this ball, which is insulated by a silk thread, to the conductor, and do you, Charles, do the same with the other. Let us now bring them together.

C. No, we cannot: they fly from one another.

T. I will hold mine to the insulated cushion, and you shall hold yours to the conductor, while the machine is turned: now I suspect they will attract one another.

J. They do indeed.

C. The reason is this, that the cushion, and whatever is in contact with it, parts with a portion of its electricity; but the conductor, and the adjoining bodies, have more than their share; therefore, the ball applied to the cushion being negatively elec-

trified, will attract the one connected with the conductor, which is positively electrified.

T. Here is a tuft of feathers, which I stick in a small hole in the conductor: now see what happens when I turn the cylinder.

J. They all endeavour to avoid each other, and stand erect in a beautiful manner. Let me take a spark from the conductor; now they fall down in a moment.

T. When I turned the wheel, they all had more than their share of the electric fluid, and therefore they repelled one another; but the moment the electricity was taken away, they fell into their natural position. A large plume of feathers, when electrified, grows beautifully turgid, expanding its fibres in all directions, and they collapse when the electricity is taken off.

J. Could you make the hairs on my head repel one another?

T. Yes, that I can. Stand on the glass-legged stool, and hold the chain that hangs on the conductor, in your hand, while I turn the machine.

C. Now your hairs stand all on end.

J. And I feel something like cobwebs over my face.

T. There are, however, no cobwebs, but that is the sensation which a person always experiences if he be highly electrified. Hold the pith ball, Charles, near your brother's face.

J. It is attracted in the same manner as it was before with the conductor.

T. Hence you may lay it down as a general rule, that all light substances coming within the influence of an electrified body are attracted by it, whether it is electrified positively or negatively.

C. Because they are attracted by the positive electricity to receive some of the superabundant quantity; and by the negative to give away some that they possess.

T. Just so: and when they have received as much as they can contain, they are repelled by the electrified body. The same thing may be shown in various ways. Having excited this glass tube, either by drawing it several times through my hand or by means of a piece of flannel, I will bring it near this small feather. See how quickly it jumps to the glass.

J. It does, and sticks to it.

T. You will observe, that, after a minute or two, it will have taken as much electricity from the tube as it can hold, when it will suddenly be repelled, and jump to the nearest conductor; upon which it will discharge the superabundant electricity that it has acquired.

J. I see it is now going to the ground, that being the nearest conductor.

T. I will prevent it, by holding the electrified tube between

it and the floor. You see how unwilling it is to come again in contact with the tube: by pursuing, I can drive it where I please without touching it.

C. That is, because the glass and the feather are both charged with the same electricity.

T. Let the feather touch the ground, or any other conductor, and you will see that it will jump to the tube as fast as it did before.

I will suspend this brass plate, which is about five inches in diameter, to the conductor, and at the distance of three or four inches below, I will place some small feathers, or bits of paper cut into the figures of men and women. They lie very quiet at present; observe their motions as soon as I turn the wheel.

J. They exhibit a pretty country dance: they jump up to the top plate, and then down again.

T. The same principle is evident in all these experiments. The upper plate has more than its own share of the electric fluid, which attracts the little figures: as soon as they have received a portion of it, they go down to give it to the lower plate; and so it will continue till the upper plate is discharged of its superabundant quantity.

I will take away the plates, and hang a chain on the conductor, the end of which shall lie in several folds in a glass tumbler; if I turn the machine, the electric fluid will run through the chain, and will electrify the inside of the glass. This done, I turn it quickly over eight or ten small pith balls, which lie on the table.

C. This is a very amusing sight: how they jump about! They serve also to fetch the electricity from the glass and carry it to the table.

T. If instead of the lower metal plate, I hold in my hand a pane of dry and very clean glass, by the corner, the paper figures, or pith balls, will not move, because glass being a non-conducting substance, it has no power of carrying away the superabundant electricity from the plate suspended from the conductor.

Take now the following results, and commit them to your memory: —

1. If two insulated pith balls be brought near the conductor, and be electrized by touching it, they will repel each other.

2. If an insulated conductor be connected with the cushion, and two insulated pith balls be electrized by it, they will repel each other.

3. If one insulated ball be electrized by the prime conductor, and another by the conductor connected with the cushion, and they be brought near, they will attract each other.

4. If one ball be electrized by glass, and another by wax, they will attract each other.

5. If one ball be electrized by a smooth, and another by a rough, excited glass tube, they will attract one another.

C. What is that you say about rough glass? You have not mentioned any difference in glass before.

T. I should have told you that bodies become differently electrized, according to the nature of the rubber; as, for instance, polished glass when rubbed with woollen cloth becomes *positively* electrized, and when rubbed with the skin of a cat becomes *negatively* electrized. The following is a list of bodies, which are negatively electrized when rubbed by a body preceding them in the list, and positively when rubbed by one following:—

Cats' skin.	Paper.
Polished glass.	Silk.
Woollen cloth,	Gum lac.
Feathers,	Rough glass.
Wood,	

CONVERSATION VI.

Of Electrical Attraction and Repulsion.

T. I will show you another instance or two of the effects of electrical attraction and repulsion.

This apparatus consists of three bells suspended from a brass wire, the two outer ones by small brass chains; the middle bell, and the two clappers *x x*, are suspended on silk. From the middle bell there is a chain N, which goes to the table, or any other conducting substance. The bells are now to be hung by C on the conductor, and the electrical machine to be put in motion.

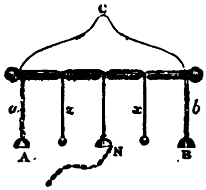


Fig. 4.

J. The clappers go from bell to bell, and make very pretty music; how do you explain this?

T. The electric fluid runs down the chains *a* and *b* to the bells A B: these, having more than their natural quantity, attract the clappers *x x*, which take a portion from A and B, and carry it to the centre bell N, and this, by means of the chain, conveys it to the earth.

C. Would not the same effect be produced if the clappers *were not* suspended on silk?

T. Certainly not: nor will it be produced if the chain be taken away from the bell N, because then there is no way left to carry off the electric fluid to the earth.

Another amusing experiment is thus made:—Let there be two wires placed exactly one above another, and parallel; the upper one must be suspended from the conductor, the other is to communicate with the table. A light image placed between these will, when the conductor is electrized, appear like a rope-dancer.

This piece of leaf-brass is called the *electric fish;* one end is a sort of obtuse angle, the other is acute; if the large end be presented towards a charged conductor, it will attach itself to it, and, from its wavering motion, will appear to be animated.

This property of attraction and repulsion has led to many inventions of instruments called electroscopes and electrometers.

J. Is not an electrometer a machine to measure the strength of the electricity?

T. Yes; and this is one of the most simple, and it depends entirely upon the repulsion which takes place between two electrized bodies. It consists of a light rod and a pith ball, hanging parallel to the stem, but turning on the centre of a semicircle, so as to keep close to its graduated limb. This is to be placed in a hole *a* on the conductor L (see fig. 2.), and accordingly as the conductor is more or less electrized, the ball will fly farther from the stem.

Fig. 5.

C. If the circular part be marked with degrees, you may, I suppose, get an idea of the strength of any given charge.

T. Yes, you may; but you see how fast the air carries away the electricity; it scarcely remains a single moment in the place to which it was repelled. Two pith balls may be suspended parallel to one another, on silken threads, and applied to any part of an electrical machine, and they will by their repulsion serve for an electrometer; for they will repel one another the more as the machine acts more powerfully.

J. Has this any advantage over the other?

T. It serves to show whether the electricity be negative or positive; for if it be positive, by applying an excited stick of sealing-wax the threads will fall together again; but if it be negative, excited sealing-wax, or resin, or sulphur, or even a rod of glass, the polish of which is taken off, will make them recede farther.

We have now perhaps said enough respecting electrical at-

traction and repulsion, at least for the present; I wish you, however, to commit the following results to your memory: —

1. Bodies that are electrized *positively* repel each other.
2. Bodies that are electrized *negatively* repel each other.

C. Do you mean that if two bodies have either more or less of the electric fluid than their natural share, they will repel each other if brought sufficiently near?

T. That is exactly what I mean.

3. Bodies electrized by contrary powers, that is, two bodies, one having more and the other less than its natural share, attract each other very strongly.
4. Bodies that are electrized attract light substances which are not electrized.

These are facts which I trust have been made evident to your senses. To-morrow we will describe what is usually called the Leyden phial.

CONVERSATION VII.

Of the Leyden Phial, or Jar.

T. I will take away the wires and the ball from the conductor, and then remove the conductor an inch or two farther from the cylinder. If the machine acts strongly, bring an insulated pith ball, that is, one hanging on silk, to the end of the conductor, nearest to the glass cylinder.

C. It is immediately attracted.

T. Carry it to the other end of the conductor, and see what happens.

C. It is attracted again; but I thought it would have been repelled.

T. Then, as the ball was electrified before and is still *attracted*, you are sure that the electricities of the two ends of the conductor are of different names; that is, one is *plus* and the other *minus*.

J. Which is the positive, and which is the negative end?

T. That end of the conductor which is nearest to the cylinder becomes possessed of an electricity different from that of the cylinder itself.

J. Do you mean, that if the cylinder is positively electrized, the end of the conductor next to it is electrized negatively?

T. I do; and this you may see by holding an insulated pith ball between them.

C. Yes; it is now very evident, for the ball fetches and *carries*, as we have seen it do before.

T. Here is a common glass tumbler: if I throw withinside it a greater portion of electricity than its natural share, and hold it in my hand, or place it on any conducting substance, as a table, a part of the electric fluid, that naturally belongs to the outside, will make its escape through my body, on the table.

C. Let me try this.

T. But you must be careful that you do not break the glass.

C. I will hang the chain on the conductor, and let the other end lie on the bottom of the glass, and James will turn the machine.

T. You must take care that the chain does not touch the edge of the glass, because then the electric fluid will run from one side of it to the other, and spoil the experiment.

J. If I have turned the machine enough, take the chain and try the two sides with the insulated pith ball.

C. What is this? something has pierced through my arms and shoulders.

T. That is a trifling electric shock which you might have avoided, if you had waited for my directions.

C. Indeed it was not trifling: I feel it now.

T. This leads us to the Leyden phial, so called because the discovery was first made at Leyden, in Holland, and by means of a phial or small bottle.

J. Was it found out in the same manner as Charles has just discovered it?

T. Nearly so. Mr. Cuneus, a Dutch philosopher, was holding a glass phial in his hand, about half filled with water, but the sides above the water and the outside were quite dry; a wire also hung from the conductor of an electrical machine into the water.

J. Did that answer to the chain?

T. Just so; and, like Charles, he was going to disengage the wire with one hand, as he held the bottle in the other, and was surprised and alarmed by a sudden shock in his arms and through his breast, which he had not the least expected.

C. I do not think there was anything to be alarmed at.

T. The shock which he felt was, probably, something severer than that which you have just experienced; but the terror was evidently increased by its coming so completely unexpected.

When M. Muschenbroek first felt the shock, which was by means of a thin glass bowl, and very slight, he wrote to M. Reaumur that he felt himself struck in his arms, shoulders, and breast, so that he lost his breath, and was two whole days before he recovered from the effects of the blow.

C. Perhaps he meant the fright.

T. Terror seems to have been the effect of the shock; for he adds, "I would not take a second shock for the whole kingdom of France."

Mr. Ninkler, an experimental philosopher at Leipsic, describes the shock as having given him convulsions, a heaviness in his head, such as he should feel if a large stone were on it, and he had reason to dread a fever, to prevent which he put himself on a course of cooling medicines. "Twice," he says, "it gave me a bleeding at the nose, to which I am not inclined; and my wife, whose curiosity surpassed her fears, received the shock twice, and found herself so weak that she could scarcely walk. Nevertheless, in the course of a few days, she received another shock, which caused a bleeding at the nose."

J. Is this called the Leyden phial?

Fig. 6.

Fig. 7.

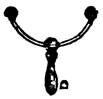


Fig. 8.

T. It is. Leyden phials are now made in this manner: A B, (fig. 6.) is a glass jar, both inside and out being covered with tinfoil about three parts of the way up, as far as *x*.

C. Does the outside covering answer to the hand, and the inside covering to the water?

T. They do. The piece of wood *z* is placed on the top, merely to support the brass wire and knob *v*, to the bottom of which hangs a chain that rests on the bottom of the jar. I will now set the jar in such a situation, that it shall be within two or three inches of the conductor, while I work the machine.

J. The sparks fly rapidly from the conductor to the knob *v*.

T. By that means the inside of the jar becomes charged with a superabundant quantity of electricity; and as it cannot contain this without, at the same time, driving away an equal quantity from the outside, the inside is charged positively, and the outside negatively. To restore the equilibrium, I must make a communication between the outside and inside with some conducting substance; that is, I must make the same substance touch at the same time the outside tinfoil and that which is within, or, which is the same thing, another substance that does touch it.

C. The brass wire touches the inside: if I, therefore, with one hand touch the knob, and with the other the outside covering, will it be sufficient?

T. It will: but I had rather you would not, because the shock will be more powerful than I should wish either you or myself to experience. Here is a brass wire with two little balls or knobs *b s* (fig. 7.) screwed to it. I will bring one of them, as *s*, to the outside, and the other, *b*, to the ball V on the wire. (See fig. 6.)

J. What a brilliant spark, and what a loud noise!

T. The electric fluid, that occasions the light and the noise, ran from the inside of the jar, through the wire to *s*, and spread itself over the outside.

C. Would it have gone through my arms if I had put one hand to the outside, and touched the wire communicating with the inside with the other?

T. It would, and you may conceive that the shock would have been in proportion to the quantity of the fluid collected. The instrument I used may be called a discharging-rod. But here is a more convenient one (fig. 8.): the handle D is solid glass, fastened into a brass socket, and the brasswork is the same as in the last figure; only by turning on a joint, the arms may be opened to any extent.

J. Why is the handle glass?

T. Because glass being a non-conductor, the electric fluid passes through the brasswork without affecting the hand; whereas, with the other, a small sensation was perceived while I discharged the jar.

C. Would the jar never discharge itself?

T. Yes; by exposure to the air for some time, the charge of the jar will be silently and gradually dissipated, for the superabundant electric fluid of the inside will escape, by means of the air, to the outside of the jar. But electricians make it a rule never to leave a jar in its charged state.

J. What is the reason of this rule?

T. To prevent accidents. A person coming into the room unawares, by touching a charged jar, might receive a shock that, under peculiar circumstances, might be attended with dangerous consequences.

There is a circumstance connected with the charging of a glass plate, or a jar, that I desire to point out: it is, that the charge is not in the metal coating, but resides on the respective surfaces of the glass. I have here a jar with movable coatings, which are of tin, like tin canisters: I place the jar in one of the tins, and place the other tin in the jar, and they thus serve as coatings.

When the jar is charged, I can remove the inner lining by a glass rod, without discharging it, and I then lift the jar out of the outer lining. I find no traces of electricity on either canister, and if there were, it would escape when I place them, as I do, on the table. But on returning them to their places, I can discharge the jar, proving that the charge remained with the glass.

CONVERSATION VIII.

Of the Leyden Jar—Lane's Discharging Electrometer, and the Electrical Battery.

C. In discharging the jar yesterday, I observed that, when one of the discharging-rods touched the outside of the jar, the flash and report took place before the other end came in contact with the brass wire that communicates with the inside coating.

T. Yes, it acts in the same manner as when you take a spark from the conductor; you do not, for that purpose, bring your knuckle close to it.

J. Sometimes, when the machine acts very powerfully, you may get the spark at the distance of several inches.

T. By the same principle, the higher an electrical or Leyden jar is charged, the more easily, or at a greater distance, is it discharged.

C. From your experiments it does not seem that it will discharge at so great a distance as that in which a spark may be taken from the conductor.

T. Very frequently a jar will discharge itself after it has accumulated as much of the electric fluid as it can contain; that is, the fluid, which is thrown on the inside coating, will make its way along the surface of the glass, to the outside coating.

J. In a Leyden jar, after the first discharge, you always, I perceive, take another and a smaller one.

T. The whole charge will not pass at first from the inside to the out: what remains is called the *residuum*, and this, in a large jar, would give you a considerable shock; therefore, I advise you always, in discharging an electrical jar, to take away the residuum before you venture to remove the apparatus. I will now describe an electrometer, which depends for its action on the principles we have been describing.

C. Do you mean upon the jar's discharging before the outside and inside coating are actually brought into contact?

T. I do. The arm D (fig. 9.) is made of glass, and proceeds from a socket on the wire of the electrical jar F. To the top of

the glass arm is cemented another brass socket E, through which a wire, with balls B and C at each end, will slide backwards and forwards.

J. So that it may be brought to any distance from the ball A, which is on the wire, connected with the inside of the jar.

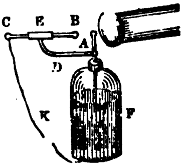


Fig. 9.

T. Just so. When the jar F is set either in contact with, or very near, the conductor as it is represented in the figure, and the ball B is set at the distance of the eighth of an inch from the ball A, let a wire K be fixed between the ball C and the outside coating of the jar. Then, as soon as the machine is worked, the jar cannot be charged beyond a certain point; for, when the charge is strong enough to pass from A to the ball B, the discharge will take place, and the electric fluid, collected in the inside, will pass through the wire K to the outside coating.

C. If you remove the balls to a greater distance from one another, will a stronger charge be required before the fluid can pass from the inside of the jar to the ball B of the electrometer?

T. Certainly: and, therefore, the discharge will be much stronger. The machine is called Lane's Discharging Electrometer, from the name of the person who invented it.

This box contains nine jars or Leyden phials: the wires, which proceed from the inside of each three of these jars, are screwed or fastened to a common horizontal wire E, which is knobbed at each extremity; and by means of the wires F F the inside coating of three or six, or the whole nine, may be connected.

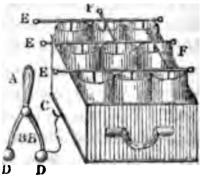


Fig. 10.

J. Is it a common box in which the jars are placed?

T. The inside of the box is lined with tinfoil; sometimes very thin plates are used, for the purpose of connecting more effectually the outside coating of the jars.

C. What is the hook C on one of the sides of the box for?

T. To this hook is fastened a strong wire, which communicates with the inside lining of the box, and that, of course, with the outside coating of the jars. And, as you see, to the hook a wire is also fastened, which connects it with one branch of the discharging rod A.

J. Is there any particular art to be used in charging a battery?

T. No: the best way is to bring a chain, or a piece of wire,

from the conductor to one of the balls E E on the rods that rest upon the jars, and then set the machine to work. The electric fluid passes from the conductor to the inside of all the jars, till they are charged sufficiently high for the purpose. Great caution, however, must be used when you come to make experiments with a battery, for fear of an accident, either to yourself or to the spectators.

C. Would a shock from this be attended with any bad consequences?

T. Yes: very serious accidents may happen from the electricity accumulated in a large battery; and even with a battery such as is represented in the figure, a shock may be given, which if passed through the head, or other vital parts of the body, may be attended with very mischievous effects.

J. How do you know when the battery is properly charged?

T. The quadrant electrometer (fig. 5.) is the best guide, and this may be fixed either on the conductor or upon one of the rods of the battery. But if it is fixed on the battery, the stem of it should be of a good length, not less than twelve or fifteen inches.

C. How high will the index stand when the battery is charged?

T. It will seldom rise so high as 90°, because a machine, under the most favourable circumstances, cannot charge a battery so high, in proportion, as a single jar. You may reckon that a battery is well charged when the index rises as high as 60°, or between that and 70°.

J. Is there no danger of breaking the jars when the battery is very highly charged?

T. Yes, there is; and if one jar be cracked, it is impossible to charge the others till the broken one be removed. To prevent accidents, it is recommended not to discharge a battery through a good conductor, except the circuit is at least five feet long.

C. Do you mean the wire should be so long?

T. Yes, if you pass the charge through a wire; but you may carry it through any conductor.

Before a battery be used, the uncoated part of the jars must be made perfectly clean and dry; for the smallest particles of dust or moisture will carry away the electric fluid. And, after an explosion, take care always to connect the wire on the hook with the ball, to prevent any residuum remaining.

J. Have not small animals been sometimes killed by an electric battery?

T. Yes: rats and mice, and pigeons have been killed instantly with discharges from a battery.

CONVERSATION IX.

Experiments made with the Electrical Battery.

T. I will now show you some experiments with this large battery. To perform these in perfect safety, I must beg you to stand a good distance from it: this will prevent accidents.

Ex. 1. I take this quire of writing-paper, and place it against the hook or wire that comes out of the box; and when the battery is charged I put one ball of the discharging-rod to a knob of one of the wires F, and bring the other knob to that part of the paper that stands against the wire proceeding from the box. You see what a hole it has made through every sheet of the paper. Smell the paper where the perforation is.

C. It smells like sulphur.

T. Or more like phosphorus. You observe, in this experiment, that the electric fluid passed from the inside of the jars, through the conducting-rod and paper, to the outside.

J. Why did it not pass through the paper in the same manner as it passed the brass discharging-rod, in which it made no hole?

T. Paper is a non-conducting substance, but brass is a conductor. Through the latter it passes without any resistance, and, in its endeavour to get to the inside of the box, it bursts the paper. The same thing would have happened had there been twice or thrice as much paper. The electric fluid of a single jar will pierce through many sheets of paper.

C. Would it serve any other non-conducting substance in the same manner?

T. Yes; it will even break a thin piece of glass, or of resin, or of sealing-wax, if it be interposed between the discharging-rod and the outside of the coating of the battery.

Ex. 2. Place a piece of loaf-sugar in the situation in which the quire of paper was just now; the sugar will be broken, and in the dark it will appear beautifully illuminated, and remain so for many seconds of time.

Ex. 3. Let the small piece of wire proceeding from the hole in the box be laid on one side of a plate, containing some spirits of wine, and on the opposite side of the plate bring one of the knobs of the discharging-rod, while the other is carried to the wires connected with the inside of the jars.

C. Then the electric fluid will have a passage through the spirit.

T. It will set it on fire instantly.

Ex. 4. Take two slips of common window-glass, about four

inches long, and one inch broad. Put a slip of gold leaf between the glasses, leaving a small part of it out at each end; then tie the glasses together, or press them with a heavy weight, and send the charge of the battery through it, by connecting one end of the glass with the outside of the jars, and bringing the discharging-rod to the other end, and to the wires of the inside of the battery.

J. Will it break the glass?

T. It probably will; but whether it does or not, the gold leaf will be forced into the pores of the glass, so as to appear like glass stained with gold, which nothing can wash away.

Ex. 5. If the gold leaf be put between two cards, and a strong charge passed through it, it will be completely fused or melted, the marks of which will appear on the card.

This instrument, called a universal discharger, is very useful for passing charges through many substances. B B are glass pillars, cemented into the frame A. To each of the pillars is cemented a brass cap, and a double joint for horizontal and vertical motion; on the top of each joint is a spring tube, which holds the sliding-wires *x x*, so that they may be set at various distances from each other, and turned in any direction. The extremities of the wires are pointed, but with screws, at about half an inch from the points, to receive balls. The table E D, inlaid with a piece of ivory, is made to move up and down in a socket, and a screw fastens it to any required height. The rings C C are very convenient for fixing a chain or wire to them, which proceeds from the conductor.

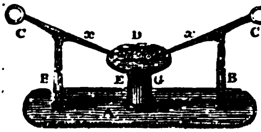


Fig. 11.

C. Do you lay anything on the ivory, between the balls, when you want to send the charges of a battery through it?

T. Yes; and by drawing out the wires the balls may be separated to any distance less than the length of the ivory. H represents a press which may be substituted in the place of the table E D. It consists of two flat pieces of mahogany, which may be brought together by screws.

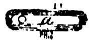


Fig. 12.

J. Then, instead of tying the slips of glass together in Ex. 4., you might have done it better by making use of the press?

T. I might; but I was willing to show you how the thing could be done, if no such apparatus as this were at hand. The *use of the* table and press, which, in fact, always go together,

is for keeping steady all descriptions of bodies through which the charge of a single jar, or any number of which a battery consists, is to be conveyed. We will now proceed with the experiments.

Ex. 6. I will take the knobs from the wires of the universal discharger, and having laid a piece of very dry writing-paper on the table E, I place the points of the wires at an inch or more from one another; then, by connecting one of the rings C with the outside wire or hook of the battery, and bringing the discharging-rod from the other ring C to one of the knobs of the battery, you will see that the paper will be torn to pieces.

Ex. 7. The experiment which I am now going to make you must never attempt by yourselves. I put a little gunpowder in the tube of a quill, open at both ends, and insert the pointed extremities of the two wires in it, so as to be within a quarter of an inch or less from each other. I now send the charge of the battery through it, and the gunpowder, you see, is instantly scattered about; and although the spark has passed through it, it is not inflamed. In order to ignite it, it is necessary to allow the charge to pass along a bad conductor, so as to present a resistance to its course. And now, if I interpose a piece of moist string in the circuit, the gunpowder is readily ignited.

Ex. 8. Here is a very slender wire, not an hundredth part of an inch in diameter, which I connect with the wires of the discharger, and send the charge of the battery through it, which will completely melt it, and you now perceive the little globules of iron instead of the thin wire.

C. Will other wires, besides iron, be melted in the same manner?

T. Yes: if the battery be large enough, and the wires sufficiently thin, the experiment will succeed with them all: even with a single jar, if it be pretty large, very slender wire may be fused.

C. That is a clear proof that the superabundant electricity accumulated in the inside is carried to the outside of the jars.

Ex. 9. I will lay this chain on a sheet of writing-paper, and send the charge of the battery through the chain; and you will see black marks will be left on the paper in those places where the rings of the chain touch each other.

Ex. 10. Place a small piece of very dry wood between the balls of the universal discharger, so that the fibres of the wood may be in the direction of the wires, and pass the charge of the battery through them; the wood will be torn in pieces. The points of the wires being run into the wood, and the shock passed through them, will effect the same thing.

Ex. 11. Here is a glass tube, open at both ends, six inches long, and a quarter of an inch in diameter. These pieces of cork, with wires in them, exactly fit the ends of the tube. I put in one cork, and fill the tube with water, then put the other cork in, and push the wire so that they nearly touch, and pass the charge of the battery through them; you see the tube is broken, and the water dispersed in every direction.*

C. If water is a good conductor, how is it that the charge did not run through it without breaking the tube?

T. The electric action converts the water into a highly elastic vapour, which, occupying very suddenly a much larger space than the water, bursts the tube before it can effect any means of escape.

In some instances, the electric fluid decomposes the water, which is instantly converted into two elastic gases, that occupy a vast deal more space than the water, from which they are produced.

CONVERSATION X.

Of the Electric Spark, and Miscellaneous Experiments.

T. I wish you to observe some facts connected with the electric spark. By means of the wire inserted in this ball I fix it to the end of the conductor, and bring either another brass ball, or my knuckle to it, and if the machine act pretty powerfully, a long, crooked, brilliant spark will pass between the two balls, or between the knuckle and ball.

C. Does the size of the spark depend at all on the size of the conductor?

T. The longest and largest sparks are obtained from a large conductor, provided the machine acts very powerfully. When the quantity of electricity is small, the spark is straight; but when it is strong, and capable of striking at a greater distance, it assumes what is called a zig-zag direction.

J. If the electric fluid is fire, why does not the spark, which excites a painful sensation, burn me, when I receive it on my hand?

T. Ex. 1. I have shown you that the charge from a battery will make iron wire red-hot, and inflame gunpowder. Now stand on the stool with glass legs, and hold the chain from the conductor with one hand. Do you, Charles, hold this spoon,

* To prevent accidents, a wire cage, such as is used in some experiments on the air-pump, should be put over the tube before the discharge is made: young persons should *not attempt* this experiment by themselves.

which contains some spirit of wine, to your brother, while I turn the machine, and a spark taken from his knuckle, if large, will set fire to the spirit.

C. It has indeed. Did you do nothing with the spirit?

T. I only made the silver spoon pretty warm before I put the spirit into it.

Ex. 2. If a ball of box-wood be placed on the conductor instead of the brass ball, a spark taken from it will be of a fine red colour.

Ex. 3. An ivory ball placed on the conductor will be rendered very beautiful and luminous, if a strong spark be taken through its centre.

Ex. 4. Sparks taken over a piece of silver leather appear of a green colour, and over gilt leather of a red colour.

Ex. 5. Here is a glass tube, round which, at small distances from each other, pieces of tinfoil are pasted in a spiral form from end to end: this tube is inclosed in a larger one, fitted with brass caps at each end, which are connected with the tinfoil of the inner tube. I hold one end A in my hand, and while one of you turn the machine, I will present the other end B to the conductor, to take sparks from it. But first shut the window-shutters.

Fig. 13.

C. This is a very beautiful experiment.

T. The beauty of it consists in the distance which is left between the pieces of tinfoil; and, by increasing the number of these distances, the brilliancy is very much heightened.

Ex. 6. The following is another experiment of the same kind. Here is a word, with which you are acquainted, made on glass, by means of tinfoil pasted on glass, fixed in a frame of baked wood. I hold the frame in my hand at H, and present the ball G to the conductor, and at every considerable spark the word is beautifully illuminated.

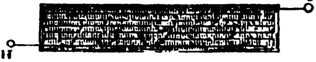


Fig. 14.

Ex. 7. A piece of sponge filled with water, and hung to a conductor, when electrified in a dark room, exhibits a beautiful appearance.

Ex. 8. This bottle is charged: if I bring the brass knob that stands out of it to a basin of water which is insulated, it will attract a drop; and, on the removal of the bottle, it will assume a conical shape, and, if brought near any conducting substance, it will fly to it in luminous streams.

Ex. 9. Place a drop of water on the conductor, and work the machine; the drop will afford a long spark, assume a conical figure, and carry some of the water with it.

Ex. 10. On this wire I have fixed a piece of sealing-wax, and, having fixed the wire into the end of the conductor, I will light the wax, and the moment the machine is worked, the wax will fly off in the finest filaments imaginable.

Ex. 11. I will wrap some cotton wool round one of the knobs of my discharging-rod, and fill the wool with finely bruised resin; I now discharge a Leyden jar, or a battery, in the common way, and the wool is instantly in a blaze. The covered knob must touch the knob of the jar, and the discharge should be effected as quickly as possible.

You will remember that the electric fluid always chooses the road presenting least resistance; in proof of which take the following experiment:

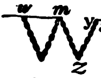


Fig. 15.

Ex. 12. With this chain I make a sort of w, the wire *w* touches the outside of a charged jar, and the wire *x* is brought to the knob of the jar, and in the dark a brilliant w is visible. But if the wire *w* is continued to *m*, the electric fluid takes a shorter road to *x*, and, of course, only half the w is seen, viz. that part marked *m z y*; but if, instead of the wire *w m*, a dry stick be laid in its place, the electric matter will prefer a longer circuit, rather than go through a bad conductor, and the whole w will be illuminated.

Ex. 13. Here is a two-ounce phial, half full of salad-oil; through the cork is passed a piece of slender wire, the end of which, within the phial, is so bent as to touch the glass just below the surface of the oil. I place my thumb opposite the point of the wire in the bottle, and in that position take a spark from the charged conductor. You observe that the spark, to get to my thumb, has actually perforated the glass. In the same way I can make holes all round the phial.

C. Would the experiment succeed with water instead of oil?

T. No, it would not.

J. At any rate we see the course of the electric fluid in this experiment; for the spark comes from the conductor down to the wire, and through the glass to the thumb.

T. Its direction is, however, better shown in this way:

Ex. 14. I will fix a pointed wire upon the prime conductor, with the point outward, and another like wire upon the insulated rubber. Shut the window-shutter, and I will work the machine: now observe the points of the two wires.

J. They both are illuminated, but differently. The point on

the conductor sends out a sort of brush of fire, but that on the rubber is illuminated with a star.

T. You see, then, the difference between the positive and negative electricity. Their appearances are sufficiently distinct in almost every experiment which can be made. If a strong positive electric stream be thrown on the flat side of an uninsulated sheet of paper, it will form a star; but negative electricity, under the same circumstances, throws out brushes.

C. Does the spark exist for any measurable time?

T. No: and this is readily proved. You see this piece of apparatus, which is nothing more than a large white disc, having a horse or other device painted on it, and fitted to a contrivance for giving it rapid rotation. I will now turn it very quickly, while the room is lighted by candles, and the horse is entirely lost; all you see is a darkish disc: I will now remove the candles, and give it a momentary light by a flash from a pistol: the horse is still invisible. But, what occurs now, when I illumine it with electric sparks?

C. Why, you have left off rotating it; it is quite still.

T. You are mistaken; it revolved as fast as ever: but the electric spark existed for so short a time, that the disc would not move over any sensible space in that time, and consequently it appeared perfectly still.

CONVERSATION XI.

Miscellaneous Experiments — Of the Electrophorus — Of the Electrometer, and the Thunder House.

T. I shall proceed this morning with some other experiments on the electrical machine.

Ex. 1. Here are two wires, one of which is connected with the outside of this charged Leyden jar, the other is so bent as easily to touch the knob of the jar. The two straight ends I bring within the distance of the tenth of an inch of one another, and press them down with my thumb, and in this position, having darkened the room, I discharge the jar. Do you look upon my thumb.

C. It was so transparent that I think I even saw the bone of the thumb. But did it not hurt you very much?

T. With attention, you might observe the principal blood-vessels, I believe; and the only inconvenience that I felt was a sort of tremor in my thumb, which is by no means painful. Had the wires been at double the distance, the shock would have probably made my thumb the circuit, which must have

caused a more powerful and unpleasant sensation; but, being so close, the electric fluid leaped from one wire to the other, and during this passage it illuminated my thumb, but did not go through it.

Ex. 2. If, instead of my thumb, a decanter full of water, having a flat bottom, were placed on the wires, and the discharge made, the whole of the water will be beautifully illuminated.

Ex. 3. This small pewter bucket is full of water, and I suspend it from the prime conductor, and put in a glass syphon, with a bore so narrow that the water will hardly drop out. See what will happen when I work the machine; but first make the room dark.

J. It runs now in a full stream, or rather in several streams, all of which are illuminated.

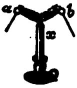


Fig. 16.

T. Ex. 4. If the knob *a* communicate with the outside of a charged Leyden jar, and the knob *b* with the inside coating, and each be held about two inches from the lighted candle *x*, and opposite to one another, the flame will spread towards each, and a discharge will be made through it: this shows the conducting power of flame.

Fig. 17.

This instrument, which consists of two circular plates, of which the largest B is about fifteen inches in diameter, and the other A fourteen inches, is called an *electrophorus*. The *under* plate B is made of glass, or sealing-wax, or of any other non-conducting substance: I have made one with a mixture of pitch and chalk boiled together, which answers very well; or of rosin, poured into a tin dish. The upper plate A is sometimes made of brass and sometimes of tin plate, but this is of wood covered very neatly with tinfoil: *x* is a glass handle fixed to a socket, by which the upper plate is removed from the under one.

C. What do you mean by an electrophorus?

T. It is, in fact, a sort of simple electrical machine, and is thus used. Rub the lower plate B with a fine piece of new flannel, or with rabbit's, or hare's, or cat's skin; and when it is well excited, place upon it the upper plate A, and put your finger on the upper plate: then remove this plate by the glass handle *x*, and, if you apply it to the knob of a coated jar, you will obtain a spark. This operation may be repeated many times, without exciting again the under plate.

J. Can you charge a Leyden jar in this way?

T. Yes, it has been done, and by a single excitation, so as to *pierce* a hole through a card by means of the jar thus charged.

Here is another kind of electrometer, which may be made exceedingly accurate; that is, it is capable of discovering the smallest quantities of electricity. A is a glass jar, B the cover of metal, to which are attached two pieces of gold-leaf *x*, or two pith balls suspended on threads: on the sides of the glass jar are two narrow strips of tinfoil, *z z*.

Fig. 18.

C. How is this instrument used?

T. Anything that is electrified is to be brought to the cover, which will cause the piece of gold-leaf, or pith balls, to diverge; and the sensibility of this instrument is so great, that the brush of a feather, the throwing of chalk, hair-powder, or dust, against the cap B evinces strong signs of electricity.

Ex. 5. Place on the cap B a little cup of pewter, or any other metal, having some water in it: then take from the fire a live cinder, and put it in the cup, and the electricity thus liberated is very admirably exhibited.

A thunder-cloud passing over this instrument will cause the slips of gold-leaf to diverge and strike the sides at every flash of lightning.

Ex. 6. I will excite this stick of sealing-wax, and bring it to the cover B: you see how often it causes the gold-leaf to strike against the sides of the glass.

J. Are the slips of tinfoil intended to carry away the electric fluid communicated by the objects presented to the cap B?

T. They are; and by them the equilibrium is restored.

CONVERSATION XII.

On Induction.

T. I must now say a few words to you upon a property of electricity termed *induction*, upon which all the other properties depend.

C. I thought all its effects originated in its attraction for matter.

T. No; this is not going to the foundation: for its attraction for matter depends on induction. Turn this machine, while I hold this light pith ball near to it: you see it is very violently attracted. But we will now take some heavier substance, which will be more quiet, and permit us to examine its condition. Here is a large brass ball, which we will suspend by a silk thread from the ceiling, near the conductor. I will now turn the machine, and you may apply your knuckle to the further side of the brass ball.

C. Why, I have obtained a spark, and yet no electricity passed from the machine to the ball.

T. True: now take the silk thread, and carry the ball carefully away from the machine, and touch it again.

C. I obtain another spark.

T. If you will now again suspend the ball near the machine, and then remove it without having previously touched it, you will not obtain a spark.

C. No, I do not; so that there appears to be some relation between the two sparks: but what most puzzles me, is how the ball is able to give these sparks, seeing that in neither case is any electricity imparted to it.

T. The effect you here observe is a capital illustration of induction. When any body, no matter how large, or how small, is charged, whether much or little, with electricity, it disturbs the natural electricity of all the bodies about it; and when these bodies are conductors, and the electricity therefore is free to move, it recedes to the side of the body most distant from the cause of disturbance. So that, in point of fact, our brass ball becomes positively electrified on its more distant side; and, consequently, negatively on its nearer side. So that, when you touched it, the positive electricity escaped; and when you afterwards moved it away from the exciting cause, it was negatively charged, for you had taken some of its electricity away, and on then touching it, you restored it to its natural state by giving it back the electricity which it required.

C. This seems very extraordinary.

T. A still more conclusive illustration is obtained by placing three insulated balls A B C in contact with each other, and facing the end of the prime conductor, A being the nearest.

While the prime conductor is charged by the rotation of the machine, A will be negative, B neutral, and C positive. If the machine is stopped and the conductor discharged, the balls will return to their natural state, the positive charge at C returning by B to A. But, if while the conductor is charged, the ball B is removed, and the conductor *then* discharged, the ball C will be found to have retained the positive charge, and A to have retained the negative; the means of neutralization having been cut off by the removal of the intermediate ball.

J. You said that all electrical phenomena were due to induction; I cannot see how this applies to the Leyden jar; for there you actually give electricity.

T. True: but I can soon show you that I cannot give it electricity, unless I allow induction to play its proper part. Place the jar on the insulating stool, and then charge it.

J. I have turned for some time, but I scarcely obtain any charge.

T. No: but now repeat the experiment, and at the same time hold the knob of another jar to the outer coating of the former.

C. Look, James, look; the sparks now enter the first jar, and actually pass through the glass, and fly off and enter the second.

T. Not so; for if you examine the first jar, you will find it very highly charged. The fact is, when you send a charge to the inner side of the jar, it disturbs the equilibrium of the outer side, and unless an escape is provided for the electricity thus elicited, further charge cannot be added to the interior; so that, in point of fact, you must allow about as much electricity to escape from the outer side as you add to the inner. Again: although the jar is very highly charged, you may take hold of the knob with impunity, so long as it stands on the insulating stool, for the charge cannot leave the inner coating until the outer coating is enabled to regain what it had lost.

C. But I cannot comprehend how this induction can occur to a thing so far removed from the inducing cause as was the brass ball in our late experiment.

T. Dr. Faraday, by dint of very patient investigation, has proved that the power is transmitted from particle to particle along the air that intervenes. Each particle of air or glass, as the case may be, becomes polarized, just as did the brass ball; but the brass ball being a conductor, that is, having the power to allow of a free movement of the electricity, the force is then manifested.

C. I should like to have some other illustration of this curious property.

T. Hold this small Leyden jar in your hand, and apply the knob to the prime conductor, until it is charged. Now take the other small jar by the knob and apply the coating to the prime conductor. By this means you obtain two jars, one positively charged, the other negatively. Now take one in each hand, and touch the two knobs together.

C. I know what will happen: the charges will neutralize each other; for, as one has more than its share, and the other less, the charge of the former will flow into the latter. Oh! oh! what a shock it gave me; how was this? I did not touch anything besides the outer coatings.

T. No: but you had forgotten that, as you charged them, induction had been necessary and had operated, so that, while the inner coatings were respectively positive and negative, the outer were negative and positive, and the two former could not be neutralized, unless the two latter were also; and this was

brought about by the intervention of your body, and you felt the effect. But if you had placed these two jars on insulating stands, and had joined their knobs by a wire, you could not discharge them so long as their outer coatings remained unconnected.

C. Does induction occur equally well through air and through glass?

T. The specific inductive capacity of bodies is various. If that of air be represented by 1, the following list will show the relative inductive capacities of certain bodies: —

Air -	- 1·00	Glass -	- 1·90
Resin -	- 1·77	Brimstone -	- 1·93
Pitch -	- 1·80	Gum-lac -	- 1·95
Bees'-wax	- 1·86		

CONVERSATION XIII.

Of Atmospherical Electricity.

C. You said that the electrometer was affected by thunder and lightning: are lightning and electricity the same?

T. They are; the demonstration of this is due to Dr. Franklin.

J. How did he ascertain this fact?

T. He was led to the theory from observing the power which uninsulated *points* have in drawing off the electricity from bodies; and having formed his system, he was waiting for the erection of a spire, in Philadelphia, to carry his views into execution, when it occurred to him that a boy's kite would answer his purpose better than a spire. He therefore prepared a kite, and having raised it, he tied to the end of the string a silken cord, by which the kite was completely insulated. At the junction of the two strings he fastened a key as a good conductor, in order to take sparks from it.

C. Did he obtain any sparks?

T. One cloud, which appeared like a thunder-cloud, passed without any effect; shortly after, the loose threads of the hempen string stood erect, in the same manner as they would if the string had been hung on an electrified insulated conductor. He then presented his knuckle to the key, and obtained an evident spark. Others succeeded before the string was wet, but when the rain had wetted the string he collected the electricity very plentifully.

J. Could I do so with our large kite?

T. I hope you will not try to raise your kite during a thunder-

storm; because, without very great care, it may be attended with the most serious danger. Professor Richmann, of St. Petersburg, was struck dead, in attempting to draw lightning from the clouds. Your kite is quite large enough for a cautious experiment, being four feet high, and two feet wide. Everything depends on the string, which, according to Cavallo, who has made many experiments on the subject, should be made of two thin threads of twine, twisted with a copper thread. And to Mr. Cavallo's work on electricity, vol. ii., such persons as are desirous of raising kites, for electrical purposes, should be referred, in which they will find ample instruction.

C. How do the conductors which I have seen fixed to various buildings act in dispersing lightning?

T. You know how easy it is to charge a Leyden jar: but if, when the machine is at work, a person hold a point of steel, or other metal near the conductor, the greater part of the fluid will run away by that point instead of proceeding to the jar. Hence it was concluded, that pointed rods would silently draw away the lightning from clouds passing over any building.

J. Is there not a particular method of fixing them?

T. Yes: the metallic rod must reach from the ground, or the nearest piece of water, to a foot or two above the building it is intended to protect; its upper termination is generally made of platinum, a metal that is not liable to rust. Large masses of metal, such as church bells, lead roofs, &c., are connected with the conductor by slips of metal, to prevent the flashes from flying off to these bodies and doing mischief. The point is partially useful in occasionally abstracting some of the charge from the cloud; but the main use of the conductor is to receive the flash itself, in case it occurs, and convey it away safely to the ground.

C. What effects would be produced if lightning should strike a building without a conductor?

T. That may be best explained by informing you of what happened, many years ago, to St. Bride's church. The lightning first struck the weathercock; from thence, descending in its progress, it beat out a number of large stones of different heights, some of which fell upon the roof of the church, and did great damage to it. The mischief done to the steeple was so considerable, that eighty-five feet were obliged to be taken down.

J. The weathercock was probably made of iron; why did not that act as a conductor?

T. Though that was made of iron, yet it was completely insulated by being fixed in stone, which had become dry by much

hot and dry weather. When, therefore, the lightning had taken possession of the weathercock, by endeavouring to force its way to another conductor, it beat down whatever stood in its way.

C. The power of lightning must be very great.

T. It is irresistible in its effects; the following experiment will illustrate what I have been saying:

Ex. 1. A is a board representing the gable end of a house.

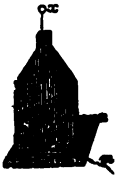


Fig. 19.

It is fixed on another board B; *a b c d* is a square hole, to which a piece of wood is fitted; *a d* represents a wire fixed diagonally on the wood *a b c d*; *x b*, terminated by the knob *x*, represents a weathercock, and the wire *c z* is fixed to the board A. It is evident that, in the state in which it is drawn in the figure, there is an interruption in the conducting-rod; accordingly, if the chain *m* is connected with the outside of a Leyden phial, and then that phial is discharged through *x*, by bringing one part of the discharging-rod to the knob of the Leyden phial, and the other to within an inch or two of *x*, the piece of wood *a b c d* will be thrown out with violence.

J. Are we to understand by this experiment, that if the wire *x b* had been continued to the chain, the electric fluid would have run through it without disturbing the loose board?

T. Ex. 2. Just so; for if the piece of wood be taken out, and the part *a* be put to the place, *b d* will come to *c*, and the conducting-rod will be complete, and continued from *x* through *b c* to *z*, and now the phial may be discharged as often as you please, but the wood will remain in its place, because the electric fluid runs through the wire to *z*, and makes its way by the chain to the outside of the phial.

C. Then, if *x* be supposed the weathercock of the church, the lightning having overcharged this, by its endeavours to reach another conductor, as *c z*, forced away the stone or stones represented by *a b c d*.

T. That is what I meant to convey to your minds by the first experiment; and the second shows very clearly, that if an iron rod had gone from the weathercock to the ground without interruption, it would have conducted away the electricity silently, and without doing any injury to the church.

J. How was it that all the stones were not beaten down?

T. Because, in its passage downwards, it met with many other conductors. I will read part of what Dr. Watson says on this fact, who examined it very attentively:

"The lightning," says he, "first took a weathercock, which

was fixed at the top of the steeple, and was conducted without injuring the metal or anything else as low as where the large iron bar, or spindle, which supported it, terminated. There the metallic communication ceasing, part of the lightning exploded, cracked, and shattered the obelisk which terminated the spire of the steeple, in its whole diameter, and threw off, at that place, several large pieces of Portland stone. Here it likewise removed a stone from its place, but not far enough to be thrown down. From thence the lightning seemed to have rushed upon two horizontal iron bars, which were placed within the building across each other. At the end of one of these iron bars it exploded again, and threw off a considerable quantity of stone. Almost all the damage was done where the ends of the iron bars had been inserted into the stone, or placed under it; and, in some places, its passage might be traced from one iron bar to another."

Electricity manifests itself more frequently without storms than with them; it is produced oftener by dry than by rainy clouds: it is more frequently positive than negative. The atmosphere exhibits signs of electricity at all times, by night and by day, of which I shall present you some instances in our next Conversation.

CONVERSATION XIV.

On Atmospheric Electricity — Of the Aurora Borealis — Of Water-spouts and Whirlwinds.

C. Does the air always contain electricity?

T. Yes; and this electricity is in a constant state of fluctuation; sometimes it is of one character, sometimes of the other; now, it is very feeble, and now is very violent.

J. Is the electrical state of the atmosphere the same at all heights?

T. No: if you take a gold electroscope terminated with a ball instead of a point, and having first touched it, so that it shall be free of electricity, and now present it to the open sky, all will be still. But if you now stand with it on a chair, or carry it a few steps up a ladder, you will observe the gold leaves diverge; if you now come down with it again the gold leaves fall back; but, if you descend below your original level, they again open. The neutral point is in all cases the place where you began the experiment.

C. I suppose this is a case of induction, not a case of charge?

T. Exactly so; and you will find that the divergence, or going

upward, was with *positive* electricity; and that on going downward was with *negative*.

J. Charles, run and fetch my large stick of sealing-wax; we will soon find this out. Thank you; now, get the steps and place them on the lawn, and then go up half way with the electrometer, and see that the leaves are still. That's right: now go up to the top; good, the leaves diverge; keep still, until I have rubbed the wax on my coat-sleeve, which, of course, charges it negatively. Take it from me, and hold it near the ball; what happens?

C. The leaves close again; and, therefore, they must have been separated by positive electricity; on removing the wax, they open again. I will now come down to my former position, when they collapse, and on coming down quite to the ground, they open again.

J. And now, when I bring the wax near, they open more widely, showing that they were under the influence of negative electricity.

T. You may vary this experiment; which, while I think of it, I ought to tell you is due to a French lover of science, M. Peltier. Go half way up the steps, as before, and see that the leaves are closed: now, mount to the top. Of course, they open: touch them, and they will close; and if you now come down to your original position, they will open, just as they did in the former experiment, when you descended below your original position. All these effects are due to the positive electricity of space.

C. What do you mean by the positive electricity of space?

T. M. Peltier taught that the earth is in the condition of a large body surcharged with negative electricity, and that space was *less negative* than the earth, and therefore positive by comparison. All the vapours that arise from the earth partake of the same negative nature as the earth whence they proceed; and by the various actions and reactions of these, he traced a host of changes in electrical tension, &c., but these are too complex for us to enter into now.

C. But the experiment you just gave us, did not enable us to collect any electricity; for the divergence we obtained was only a case of induction, which ceased as soon as the inducing cause was removed. Are there no means of collecting small quantities of electricity from the atmosphere?

T. Oh, yes, several. If the electrometer, in the above experiment, had been furnished with a point, instead of a ball, the leaves would have diverged, as before, on ascending with it; but they would not collapse on descending, for the point would

have permitted a charge to pass in, and the instrument when brought to its original level would have been charged.

J. Is this the mode employed at electrical observatories?

T. No: at Kew there is a very famous apparatus, under the direction of Mr. Ronalds. A brass rod rises from a glass leg placed on a table, and kept carefully dry by means of a lamp constantly burning. A lighted lamp is hoisted to the top of the rod, the flame of which is an excellent collector of electricity; and the rod conducts what is collected to proper instruments placed on the table beneath. The late Mr. Weekes, of Sandwich, and Mr. Crosse, of Broomfield, had long lengths of wire suspended in the air, by means of which very large quantities of electricity were collected. In all these cases, lightning conductors were attached, which came into operation in case of accident.

J. Since lofty objects are exposed to the effects of lightning, or the electric fluid, do not the tall masts of ships run considerable risk of being struck by it?

T. Certainly: we have many instances recorded of the mischief done to ships; one which is related in the "Philosophical Transactions:" it happened on board the Montague, on the 4th of November, 1748, in latitude 42° 48′, and 9° 3′ west longitude, about noon. One of the quarter-masters desired the master of the vessel to look to the windward, when he observed a large ball of blue fire rolling apparently on the surface of the water, at the distance of three miles from them. It rose almost perpendicular, when it was within forty or fifty yards from the main-chains of the ship; it then went off with an explosion, as if a hundred cannons had been fired at one time, and left so strong a smell of sulphur, that the ship seemed to contain nothing else. After the noise had subsided, the main topmast was found shattered to pieces, and the mast itself was rent quite down to the keel. Five men were knocked down, and one of them greatly burnt by the explosion.

C. Did it not seem to be a very large ball to have produced such effects?

T. Yes; the person who noticed it said it was as big as a millstone.

C. Are no means adopted for protecting ships?

T. Yes: the plan adopted by Her Majesty's government, which is decidedly the best plan, was proposed by Sir. W. Snow Harris. Wide and thick slips of sheet copper are let into the wood of the masts, and other similar parts of the ship, and are kept in sound metallic connexion as far as the copper sheathing of the vessel; they are connected with this by bolts, passing

through the bottom of the ship. The best proof of the security of this plan is, that no ship thus fitted up has been damaged by lightning.

C. What is the *aurora borealis?*

T. The *aurora borealis* is another electrical phenomenon: this is admitted without any hesitation, because electricians can readily imitate the appearance with their experiments.

J. It must be, I should think, on a very small scale.

T. True; there is a glass tube about thirty inches long, and the diameter of it is about two inches: it is nearly exhausted of air, and capped on both ends with brass. I now connect these ends, by means of a chain, with the positive and negative part of a machine; and in a darkened room you will see, when the machine is worked, all the appearances of the northern lights in the tube.

C. Why is it necessary nearly to exhaust the tube?

T. Because the air, in its natural state, is a very bad conductor of the electric fluid; but when it is, perhaps, rendered some hundred times rarer than it usually is, the electric fluid darts from one cap to the other with the greatest ease.

J. But we see the aurora borealis in the common air.

T. We do so; it is, however, in the higher regions of the atmosphere, probably 70 or 80 miles high, where the air is much rarer than it is near the surface of the earth. The experiment which you have just seen accounts for the darting and undulating motion which takes place between the opposite parts of the heavens. The aurora borealis is the most beautiful and brilliant in countries in the high northern latitudes, as in Greenland and Iceland.

The aurora borealis that was seen in this country on the 23rd of October, in the year 1804, is deserving of notice. At seven in the evening, a luminous arch was seen from the centre of London extending from one point of the horizon, about S.S.W. to another point N.N.W., and passing the middle of the constellation of the Great Bear, which it, in a great measure, obscured. It appeared to consist of shining vapour, and to roll from the south to the north. In about half an hour its course was changed; it then became vertical, and about nine o'clock it extended across the heavens from N.E. to S.W.; at intervals the continuity of the luminous arch was broken, and there then darted from its south-west quarters, towards the zenith, strong flashes and streaks of bright red, similar to what appears in the atmosphere during a great fire in any part of the metropolis. For several hours the atmosphere was as light in the south-west as if the sun had set but half an hour; and the light in the north resembled

the strong twilight which marks that part of the horizon at Midsummer.

C. I have heard that the needles of the electric telegraph are affected during the times of aurora borealis.

T. Yes; and so are also the standard magnetic bars in observatories: which two simultaneous effects point out remarkable relations between the changes in the natural magnetic force of the earth, and natural electric currents. From the effect on the magnetic needle, these phenomena are often called "Magnetic Storms." And, when telegraph needles are thus disturbed, it may safely be predicted that unusual variations are being manifested by the magnetic needle; and when night comes on, aurora will surely be seen. In some years these storms are very frequent; about three years ago, they were so troublesome that Mr. C. V. Walker was compelled to apply a contrivance to the telegraph in order to neutralise their ill-effects.

J. I think I have heard that *water-spouts*, which are sometimes seen at sea, arise from the power of electricity, and not from the force of the wind.

T. The wind will not account for every appearance connected with them. Water-spouts are often seen in calm weather, when the sea seems to boil, and send up a smoke under them, rising in a sort of hill towards the spout. A rumbling noise is often heard at the time of their appearance, which happens generally in those months that are peculiarly subject to thunder-storms, and they are commonly accompanied or followed by lightning.

Water-spouts at sea are undoubtedly very like whirlwinds and hurricanes by land. These sometimes tear up trees, throw down buildings, make caverns; and, in all the cases, they scatter the earth, bricks, stones, timber, &c., to a great distance in every direction. Dr. Franklin mentions a remarkable appearance which occurred to Mr. Wilkie, an electrician. On the 20th of July, 1758, at three o'clock in the afternoon, he observed a great quantity of dust rising from the ground, and covering a field and part of the town in which he then was. There was no wind, and the dust moved gently towards the east, where there appeared a great black cloud, which electrified his apparatus positively to a very high degree. This cloud went towards the west, the dust followed it, and continued to rise higher and higher, till it composed a thick pillar, in the form of a sugar-loaf, and at length it seemed to be in contact with the cloud. At some distance from this, there came another great cloud, with a long stream of smaller ones, which electrified his apparatus negatively, and when they came near the positive cloud a flash of lightning was seen to dart through the cloud of dust; upon

which the negative clouds spread very much, and dissolved in rain, which presently cleared the atmosphere.

C. Is rain, then, an electrical phenomenon?

T. The most enlightened and best-informed electricians reckon rain, hail, and snow among the effects produced by the electric fluid.

J. Do the negative and positive clouds act in the same manner as the outside and inside coatings of a charged Leyden jar?

T. Thunder-clouds frequently do nothing more than conduct or convey the electric matter from one place to another.

C. Then they may be compared to the discharging-rod.

T. The following is not an uncommon appearance: a dark cloud is observed to attract others to it, and, when grown to a considerable size, its lower surface swells in particular parts towards the earth. During the time that the cloud is thus forming, flashes of lightning dart from one part of it to the other, and often illuminate the whole mass; and small clouds are observed moving rapidly beneath it. When the cloud has acquired a sufficient extent the lightning strikes the earth in two opposite places.

CONVERSATION XV.

Medical Electricity.

T. Physicians have applied electricity medically; in some cases their endeavours have been unavailing, in others the success has been very complete.

C. Did they do nothing more than this?

T. Yes; in some cases they took sparks from their patients, in others they gave them shocks.

J. This would be no pleasant method of cure, if the shocks were strong.

T. You know by means of Lane's electrometer, described in our seventh Conversation, the shock may be given as slightly as you please.

C. But how are shocks conveyed through any part of the body?

T. There are machines and apparatus made expressly for medical purposes. Suppose the electrometer to be fixed to a Leyden phial, and the knob at A to touch the conductor, and the knob at B to be as far off as you mean the shocks to be weak or strong, a chain or wire of sufficient length is to be fixed to the ring C of the electrometer, and another wire or chain to the outside coating: the other ends of these two wires are to be fastened to the two knobs of the discharging-rod.

J. What next is to be done, if I wish to electrify my knee, for instance?

T. All you have to do is to bring the balls of the discharging-rod close to your knee, one on the one side, and the other on the opposite side.

C. And, at every discharge of the Leyden jar, the superabundant electricity from withinside will pass from the knob at A to the knob B, and will pass through the wire and the knee, in its way to the outside of the jar, to restore to both sides an equilibrium.

J. But if it happen that a part of a body, as an arm, is to be electrified, how is it to be done, because in that case I cannot use both my hands in conducting the wires?

T. Then you may seek the assistance of a friend, who will, by means of two instruments, called *directors*, be able to conduct the fluid to any part of the body whatever.

C. What are directors?

T. A director consists of a knobbed brass wire, which, by means of a brass cap, is cemented to a glass handle. So the operator, holding these directors by the extremities of the glass handle, brings the balls, to which the wires or chains are attached, into contact with the extremities of that part of the body of the patient through which the shock is to be sent. If I feel rheumatic pains between my elbow and wrist, and a person hold one director at the elbow and another about the wrist, the shock will pass through, and probably will be found useful in removing the complaint.

J. Is it necessary to stand on the glass-footed stool to have this operation performed?

T. By no means: when shocks are administered, the person who receives them may stand as he pleases, either on the stool, or on the ground; the electric fluid, taking the nearest passage, will always find the other knob of the other director, which leads to the outside of the jar.

C. Is it necessary to make the body bare?

T. Not in the case of shocks, unless the coverings be very thick: but when sparks are to be taken, then the person from whom they are drawn must be insulated, and the clothes should be stripped off the part affected.

J. For what disorders is electricity chiefly used?

T. Dr. Golding Bird, an eminent physician at Guy's Hospital, has published a series of lectures, in which he gives the results of the application of electricity to different classes of disease.

In eleven cases of paralysis, five were cured, four improved, and two not relieved. Sparks were taken from the spine. Of ten cases of rheumatic paralysis, five were cured, three relieved,

and two unrelieved. Sparks were taken from the spine, and from the muscles that were affected. Equal success attended his applications of electricity to the relief of other ills to which flesh is heir.

CONVERSATION XVI.

Of Animal Electricity; of the Torpedo; of the Gymnotus Electricus; and of the Silurus Electricus.

T. There are certain fish which are possessed of the singular property of giving shocks very similar to those experienced by means of the Leyden jar.

C. I should like much to see them: are they easily obtained?

T. No, they are not: they are called the *torpedo*, the *gymnotus electricus*, and the *silurus electricus.*

J. Are they all of the same genus?

T. No; the torpedo is a flat fish, seldom twenty inches long, and is common in various parts of the sea coast of Europe. The electric organs of this fish are placed on each side of the gills, where they fill up the whole thickness of the animal, from the lower to the upper surface, and are covered by the common skin of the body.

C. Can you lay hold of the fish by any other part of the body with impunity.

T. Not altogether so; for if it be touched with one hand, it generally communicates a very slight shock; but if it be touched with both hands at the same time, one being applied to the under, and the other to the upper surface of the body, a shock will be received similar to that which is occasioned by the Leyden jar.

J. Will not the shock be felt if both hands be put on one of the electrical organs at the same time?

T. No; and this shows that the upper and lower surfaces of the electric organs are in opposite states of electricity, answering to the positive and negative sides of a Leyden phial.

C. Are the same substances conductors of the electric power of the torpedo, by which artificial electricity is conducted?

T. Yes, they are: and if the fish, instead of being touched by the hands, be touched by conducting substances, as metals, the shock will be communicated through them. The circuit may also be formed by several persons joining hands, and the shock will be felt by them all at the same time.

C. Is it known how the power is accumulated?

T. It seems to depend on the will of the animal, for each effort is accompanied with a depression of its eyes, and it probably makes use of it as a means of self-defence.

J. Is this the case also with the other electrical fishes?

T. The *gymnotus* possesses all the electric properties of the torpedo, but in a very superior degree. This fish has been called the electrical eel, on account of its resemblance to the common eel. It is found in the large rivers of South America.

C. Are these fishes able to injure others by this power?

T. If small fishes are put into the water in which the gymnotus is kept, it will first stun, or perhaps kill them, and if it be hungry, it will then devour them. But fishes stunned by the gymnotus may be recovered, by being speedily removed into another vessel of water.

In March, 1838, a gymnotus was caught and sent safely to England, and was received at the Adelaide Gallery on August 15th. In September of the same year, Dr. Faraday experimented with it, and obtained from it electricity which produced all the usual effects. The *shock* was most powerful when one hand grasped it near the head, and the other near the tail. The needle of a *galvanometer* (an instrument to be described hereafter) was *deflected* 40°; the positive electricity passing from the anterior part of the body, through the galvanometer, to the posterior part. A needle was *magnetized*, by allowing the electricity to pass through twenty-five feet of silk-covered wire, wound round a quill, in which the needle was placed.

Chemical decomposition was easily obtained by allowing the electricity to pass through paper moistened by a solution of iodide of potassium. *Heat* was produced by allowing the discharge to take place through a fine wire, contained in a glass globe of air. The *electric spark* was obtained by having one end of the wire of an electro-magnet in contact, by proper conductors, with the fish, while the other was rubbed along a file.

C. But you are telling us of apparatus that have not been mentioned before; and we cannot know how they act.

T. I mention them here, as I am describing the power of this fish; but must reserve the explanation of them until we get into the secrets of voltaic electricity and electro-magnetism.

I should have told you, that a direct spark was obtained between the leaves of a gold-leaf electroscope.

M. Gassiot obtained not only the *attraction* of gold-leaves, but they were actually fused, scintillating in a beautiful manner.

This gymnotus died of the rupture of a blood-vessel on March 14th, 1842.

Several others have since reached England, of which live specimens are to be seen at the Royal Polytechnic Institution.

Some, coming as presents to the Electrical Society, died on their passage, of which careful dissections were made by Dr. Letheby of the London Hospital. The electrical organs, preserved in spirit, may be seen at the Polytechnic.

J. How do they catch these kinds of fish; the man would, probably, let them go on receiving the shock?

T. In this way the property was, perhaps, first discovered. The gymnotus, as well as the others, may be touched, without any risk of the shock, with wax or with glass; but if it be touched with the naked finger, or with a metal, or a gold ring, the shock is felt upon the arm.

C. Does the *silurus electricus* produce the same effects as the others?

T. This fish is found in some river in Africa, and it is known to possess the property of giving the shock, but no other particulars have been detailed respecting it.

With regard to the torpedo, its power of giving the benumbing sensation was known to the ancients, and from this it probably took its name. In Firmin's "Natural History of Surinam" is some account of the *trembling eel*, which Dr. Priestly conjectures to be different from the gymnotus; it lives in marshy places, from whence it cannot be taken, except when it is intoxicated. It cannot be touched with the hand, or with a stick, without giving a terrible shock. If trod upon with shoes, the legs and thighs are affected in a similar manner.

The enterprising scientific traveller Humboldt enables us to give a very satisfactory answer to James's inquiry as to the mode of catching these electric fishes. When he was in South America he was exceedingly anxious to obtain some of these animals for his experiments. For this express purpose he stopped some days, on his journey across the Llanos to the river Apure, at the small town of Calabozo, in the neighbourhood of which he was informed that they were very numerous. He was conducted to the Cano de Bera, the principal spot frequented by the *gymnoti*. It is a small piece of shallow water, stagnant and muddy, but of the heat of seventy-nine degrees, and surrounded by a rich vegetation. Here he soon witnessed a spectacle of the most novel and extraordinary kind. About thirty horses and mules were quickly collected from the adjacent savannahs, where they run half wild, and are only valued at a few shillings each. These the Indians hem in on all sides, and drive into the marsh; then pressing to the edge of the water, or climbing along the extended branches of the trees, armed with long bamboos or harpoons, they, with loud cries, push the animals forward, and prevent their retreat. The

gymnoti, roused from their slumbers by this noise and tumult, mount near the surface, and, swimming like so many livid water serpents, briskly pursue the intruders, and, gliding under their bellies, discharge through them the most violent and repeated shocks. The horses, convulsed and terrified, their manes erect, and their eyes staring with pain and anguish, make unavailing struggles to escape. In less than five minutes, two of them sunk under the water, and were drowned. Victory seemed to declare for the electric eels: but their activity now began to relax. Fatigued by such expense of nervous energy, they shot their electric discharges with less frequency and effect. The surviving horses gradually recovered from the shocks, and became more composed and vigorous. In a quarter of an hour the *gymnoti* finally retired from the contest, and in such a state of languor and complete exhaustion, that they were easily dragged on shore by the help of small harpoons fastened to cords. This very singular method of catching the electric eel is, in allusion to the mode of catching fish by means of the infusion of narcotic plants, termed *embarbascar con caballos*, or *poisoning with horses!*

CONVERSATION XVII.

General Summary of Electricity, with Experiments.

T. You now understand that electricity pervades all substances, and, when undisturbed, it remains in a state of equilibrium.

J. And that certain portion, which every body is supposed to contain, is called its natural share.

T. When a body is possessed of more or retains less than its natural share, it is said to be *charged*, or electrified.

C. If it possess more than its natural share, it is said to be *positively* electrified; but if it contain less than its natural share, it is said to be *negatively* electrified.

T. Does it not sometimes happen that the same substance is both positively and negatively electrified at the same time?

J. Yes: the Leyden jar is a striking instance of this, in which, if the inside contain more than its natural share, the outside will contain less than its natural quantity.

T. What is the distinction between conductors and non-conductors of electricity?

C. The electric fluid passes more freely through the *former* than the *latter*.

T. You know that electricity is excited in the greatest quantities by the friction of conducting and non-conducting substances against each other.

Ex. Rub two pieces of sealing-wax, or two pieces of glass, together, and only a very small portion of electricity can be obtained: therefore the rubber of a machine should be a conducting substance, and not insulated.

Every electrical machine, with an insulated rubber, will act in three different ways: the rubber will produce *negative* electricity; the conductor will give out *positive* electricity; and it will communicate both powers at once to a person or substance placed between two directors connected with them.

J. How does the rubber produce negative electricity?

T. If you stand on a stool with glass legs, or upon any other non-conducting substance, and lay hold of the rubber, or a chain that communicates with it, the working the machine will take away from you a quantity of your natural electricity: therefore you will be negatively electrified.

C. Will this appear by the nature of the electric fluid, if I hold in my hand a steel point, as a needle?

T. If you, standing on a non-conducting substance, are connected with the rubber, and your brother, in a similar situation, connected with the conductor, hold points in your hands, and I, while I stand on the ground, first present a brass ball, or other substance, to the needle in your hand, and then to that in his hand, the appearance of the fluid will be different in both cases: to the needle in your hand it will appear like a star, but to that in your brother's it will be rather in the form of a brush. What will happen if you bring two bodies near to one another that are both electrified?

J. If they are both positively or both negatively electrified, they will repel each other; but if one is negative and the other positive they will attract one another till they touch, and the equilibrium is again restored.

T. If a body containing only its natural share of electricity, be brought near to another that is electrified, what will be the consequence?

C. A quantity of electricity will force itself through the air in the form of a spark.

T. When two bodies approach each other, one electrified positively and the other negatively, the superabundant electricity rushes violently from one to the other to restore the equilibrium. What will happen if your body, or any part of it, form part of the circuit?

J. An electric shock will be produced, and if, instead of one

person alone many join hands and form part of the circuit, they will all receive a shock at one and the same instant.

T. If I throw a larger quantity of electricity than its natural share on one side of a piece of glass, what will happen to the other side?

C. The other side will become negatively electrified: that is, it will have about as much less than its natural share as the other has more than its natural share.

T. Does electricity communicated to glass spread over the whole surface?

J. No: glass being an excellent non-conductor, the electric fluid will be confined to the part on which it is thrown; and for that reason, and in order to apply it to the whole surface, the glass is covered with tinfoil, which is called a *coating*.

T. And if a conducting communication be made between both sides of the glass, what takes place then?

C. A discharge; and this happens whether the glass be flat or in any other form.

T. What do you call a cylindrical glass vessel, thus coated for electrical purposes?

J. A Leyden jar; and when the insides, and also the outsides, of several of these jars are connected, it is called an electrical battery.

T. Electricity in this form is capable of producing the most powerful effects, such as melting metals, firing spirits, and other inflammable substances. What effect have metallic points on electricity?

C. They discharge it silently, and hence their great utility in defending buildings from the dire effects of lightning. Pray, what is thunder?

T. As lightning appears to be the rapid motion of vast masses of electric matter, so thunder is the noise produced by the motion of lightning; and when electricity passes through the higher parts of the atmosphere, where the air is very much rarefied, it constitutes the aurora borealis.

Ex. If two sharp-pointed wires be bent with the four ends at right angles, but pointing different ways, and they be made to turn upon a wire *x* fixed on the conductor, the moment it is electrified a flame will be seen at the points *a b c d*; the wire will begin to turn round in the direction opposite to that to which the points are turned, and the motion will become very rapid.

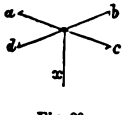


Fig. 20.

If the figures of horses cut in paper be fastened upon these wires, the horses will seem to pursue one another; and this is

called the electrical horse-race. Of course, upon this principle, many other amusing and very beautiful experiments may be made; and upon the same principle several electrical orreries have been contrived, showing the motions of the earth and moon, and the earth and planets round the sun.

J. How do you account for this?

T. Fix a sharp-pointed wire into the end of the large conductor, and hold your hand near it; no sparks will ensue; but a cold blast will come from the point, which, when applied to light mills, wheels, &c., will turn them with great velocity.

VOLTAIC ELECTRICITY.

CONVERSATION I.

Of Galvanism — Its Origin — Experiments — Of the Decomposition of Water.

T. It has been observed as long as I can remember, and probably before I was born, that porter, when taken from a pewter pot, had a superior flavour than when drunk out of glass or china.

C. Yes; I have often heard people say so; but what is the reason of it?

T. Admitting the fact, which is, I believe, generally allowed by those who are much accustomed to drink that beverage, it is explained upon principles which are now well understood.

J. And are these principles electrical?

T. Yes; but before I speak of them I should tell you that the branch of science to which they belong was termed Galvanism, from Dr. Galvani, who first reported to the philosophical world the experiments on which the science is founded; but it is now more generally termed Voltaic Electricity, because the chemical features of the science, on which most of the illustrations are based, are due to the original discoveries of Volta.

C. What, then, did Galvani do?

T. Galvani, a professor of anatomy at Bologna, was making some electrical experiments, and on the table where the machine stood were some frogs skinned. On touching the main nerve of a frog, at the same moment that he took a considerable spark from the conductor of the electrical machine, the muscles of the frog were thrown into strong convulsions. The Professor made a number of other experiments; but as they cannot be repeated without much cruelty to living animals, I shall not enter into a detail of them.

J. Were not the frogs dead which first led to the discovery?

T. Yes, they were; but the Professor afterwards made many experiments upon living ones, whence he found that the convulsions, or, as they are usually called, the contractions pro-

duced on the frog may be excited merely by making a communication between the nerves and the muscles with substances that are *conductors* of electricity.

To illustrate what I mean, you may take a piece of zinc plate and lay upon it a half-crown; place a leech or a slug upon the half-crown, and mark what follows.

C. I see nothing remarkable; the leech moves as might be expected. Oh! look there; what made him start? There he is again! why it seems that the moment he touches the zinc he is convulsed.

T. He is so, providing he is at the same time touching the silver; if he were on the zinc alone nothing would happen. The fact is, that when two metals and a liquid are in contact, so as to form a circle, electricity is generated. In this case, the moisture on the surface of the animal serves as the liquid. One metal and two liquids properly arranged produce analogous effects; and thus, when the moisture of the mouth, the porter, and the pewter pot were associated, a pungent taste was produced on the tongue, which improved the flavour of the liquid. You may have noticed, doubtless, that a silver spoon dipped in an egg is not discoloured; but one that has been used for eating an egg is very much so. The reason of this is that in the latter case, the metal, the moisture of the mouth, and the egg form a voltaic circle, and produce a current of electricity, attended by a chemical decomposition, which discolours the spoon.

I will show you an experiment on the subject. Here is a thin piece of zinc; lay it *under* your tongue, and lay this half-crown *upon* the tongue. Do you taste anything very peculiar in the metals?

J. No; nothing at all.

T. Put them in the same position again, and now bring the edges of the two metals into contact, while the other parts touch the under and upper surface of the tongue.

J. Now they excite a very disagreeable taste, something like copperas.

T. Instead of the half-crown, try the experiment with a guinea, or with a piece of charcoal.

C. I perceive the same kind of taste which James described; and I can see that when we make the edges touch, we form a voltaic circle, and then *taste* its effects; but while the edges are apart, the circle is incomplete, and the effect ceases.

J. All metals, as we have seen, are conducting substances; of course, the zinc, the guinea, and the half-crown are conductors.

T. Yes; and so are the tongue and the saliva; and by the *decomposition* of some small particles of the saliva, the sharp *taste is excited.*

C. What do you mean by the decomposition of the saliva?

T. Chemistry teaches us that water is capable of being decomposed, that is, separated into two gases, called hydrogen and oxygen.

J. Is saliva capable of being thus separated?

T. Certainly; because a great part of it may be supposed to be water; and the oxygen combines with the metal, while the hydrogen escapes.

C. The disagreeable taste on the tongue cannot be disputed; but there is no apparent change on the zinc or the half-crown, which there ought to be if a new substance, as the oxygen, has entered into the combination.

T. The change is, perhaps, too small to be perceived in this experiment; but in others on a larger scale it will be very evident to the sight, by the *oxidation* of the metals.

J. Here is another strange word. I do not know what is meant by oxidation.

T. The iron bars fixed before the window were clean and almost bright when placed there last summer.

J. But not being painted they are become quite rusty.

T. Now, in chemical language, the iron is said to be oxidated instead of rusty; and the earthy substance that may be scraped from them used to be called the *calx* of iron; but it is, by modern chemistry, denominated the oxide of iron.

When mercury loses its fine brightness, by being long exposed to the air, the dullness is occasioned by oxidation; that is, the same effect is produced by the air on the mercury as was on the iron. I will give you another instance. I will melt some lead in this ladle; you see a scum is speedily formed. I take it away, and another will arise, and so perpetually, till the whole lead is thus transformed into an apparently different substance. This is called the oxide of lead.

On the same principle we obtain the oxides of the other metals; and the process by which the metals are converted into oxides is called oxidation. The pure metals, as silver and gold, are not easily oxidated; but lead, copper, iron, zinc, &c., readily lose their metallic properties, and become oxides.

CONVERSATION II.

Galvanic Light and Shocks — Voltaism.

C. We had a *taste* of voltaic electricity yesterday. Is there no way of seeing it?

T. Put this piece of zinc between the lip and the gums, as

high as you can, and then lay a half-crown, or guinea, upon the tongue, and, when so situated, bring the metals into contact.

C. I thought I saw a faint flash of light.

T. I dare say you did; it was for that purpose I bade you make the experiment. It may be done in another way; by putting a piece of silver up one of the nostrils, and the zinc on the upper part of the tongue, and then bringing the metals in contact, the same effect will be produced.

J. By continuing the contact of the two metals, the appearance of light does not remain.

T. No, it is visible only at the moment of making the contact. You may, if you make the experiment with great attention, put a small slip of tinfoil over the ball of one eye, and hold a teaspoon in your mouth, and then, upon the communication between the spoon and the tin, a faint light will be visible. These experiments are best formed in the dark.

C. Are there no means of making experiments on a larger scale?

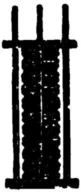


Fig. 1.

T. Yes, we have galvanic (or as they ought to be denominated, *voltaic* batteries, from Volta, the inventor of them) as well as electrical batteries. Here is one of them (Fig. 1.). It consists of a number of pieces of silver, zinc, and flannel cloth, of equal sizes; and they are thus arranged: a piece of zinc, a piece of silver, and a piece of cloth moistened with a solution of salt in water, and so on till the pile is completed. To prevent the pieces from falling, they are supported on the sides by three rods of glass fixed into a piece of wood, and down these rods slides another piece of wood, which keep all the pieces in close contact. Copper may be used instead of silver, but requires to be cleaned more frequently.

J. How do you make use of this instrument?

T. Touch the lower piece of metal with one hand, and the upper one with the other.

J. I felt an electric shock.

T. And you may take as many as you please; for, as often as you renew the contact, so often will you feel the shock. Here is a different apparatus (Fig. 2.). In these three glasses (and I might use 30, or 300, or more, as well as three) is a solution of salt and water. Into each, except the two outer ones, is plunged a small plate of zinc, and another of silver or copper. These plates are made to communicate with each other by means of a thin wire, fastened so that the silver of the first glass is connected with the zinc of the second; the

Fig. 2.

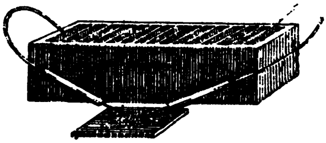


Fig. 3.

silver of the second with the zinc of the third, and so on: now, if you dip one hand into the first glass, and the other into the last, the shock is felt.

C. Will any kind of glasses answer for this experiment?

T. Yes, they will; wine-glasses, or goblets, or finger glasses, and so will china cups.

A third kind of battery (Fig. 3.) consists of a trough of wood, three or four inches deep, and about as broad. In the sides of this trough are grooves opposite to each other, and about a quarter of an inch asunder. Into each pair of these grooves is put a plate of zinc, and another of copper, and they are to be cemented in such a manner as to prevent any communication between the different cells. The cells are now filled with a solution of salt and water; or, if you wish to have the battery more powerful, with dilute-sulphuric acid; or, if still more powerful, with a mixture of dilute-sulphuric and nitric acids: but in these latter cases, the liquids must not be poured in until the batteries are actually required, and must be poured out as soon as the experiments are over; as they act spontaneously and powerfully upon the zinc.

In the various voltaic combinations, where powerful acids are used, the zinc is profitably protected by being first well scoured with sand and acid, and then dipped into mercury. This is called *amalgamation*. The battery is complete; with your hands make a communication between the two end cells.

C. I felt a strong shock.

T. Wet your hands, and join your left with James's right, then put your right hand into one end cell, and let James put his left into the opposite one.

J. We both felt the shock like an electric shock, but not so severe.

T. Several persons may receive the shock together, by joining hands, if their hands are well moistened with water. The strength of the shock is much diminished by passing through so long a circuit. The shock from a battery consisting of fifty or sixty pairs of zinc and silver, or zinc and copper, may be felt as

high as the elbows. And if five or six such batteries be united with metal clamps, the combined force of the shock would be such that few would willingly take it a second time.

C. What are the wires for at each end of the trough?

T. They are attached in order that the electric force may be directed into such channels as will make it manifest; for instance, if a small piece of well-burnt box-wood charcoal is tied at the end of each wire, and the charcoal points are brought together, and then slightly separated, the *electric light* is produced, and the charcoal is slightly consumed.

An apparatus has been constructed by which the points adjust themselves in proportion as they are consumed; and voltaic batteries have been proposed for producing electricity at a *cheap rate*. When these things are practically carried out, we shall have electric illumination.

C. How valuable this will be for single large lights, although not so convenient in a room!

T. The *heating power* of an electric current is shown by straining a small platinum wire between the two short copper wires; this metal is a comparatively bad conductor of electricity, and is immediately made incandescent, and gives out much heat, and no small amount of light. If one wire is placed in a cup of mercury, and gold or silver-leaf, hanging from the other, is allowed to flap upon the mercury, the leaf ignites and burns with a beautiful flame; which varies with the different metals.

Chemical action is shown by dipping the ends of the wires into some liquid. Changes then occur in the neighbourhood of each wire, which are dependent on the nature of the liquid, and of the wires. If, for instance, the liquid is dilute sulphuric acid, and the metal platinum, the water of the solution is decomposed, and its constituents are liberated; viz. oxygen gas, where the current enters the solution, and hydrogen where it leaves it: if the current enters by a copper wire, the oxygen, instead of appearing, unites with the copper, and makes an oxide of copper, which is immediately dissolved; if much oxide of copper is allowed to dissolve in, the hydrogen will soon cease to appear at the wire by which the current leaves the solution; for the hydrogen, in this case, exchanges places with the copper that is in solution, and the copper makes its appearance in a bright metallic form.

Magnetic deflection is shown by joining the wires together, and holding them near a compass needle and parallel with it. The needle moves according to certain laws, to which we will briefly refer in our conversation on electro-magnetism.

Magnets are easily *made* by wrapping a portion of the wire

(which must be covered with cotton or silk, &c. for this purpose) round a steel or iron bar; in the former case a permanent magnet is made, in the latter a temporary magnet.

By leading these wires to two separate gold-leaves of an electroscope of special construction, *attraction* is obtained. And by using a proper kind of battery and many cells, a *spark* passes before the wires quite meet.

J. Will the battery continue to act any great length of time?

T. The action of all these kinds of batteries is the strongest when they are first filled with the fluid; and it declines in proportion as the metals are oxidated, or the fluid loses its power. Of course, after a certain time, the fluid must be changed and the metals cleaned, either with sand, or by immersing them a short time in diluted acid. Care must always be taken to wipe quite dry the edges of the plates, to prevent a communication between the cells: and it will be found, that the energy of the battery is in proportion to the rapidity with which the zinc is oxidated.

CONVERSATION III.

Voltaic Conductors — Circles — Tables — Experiments.

T. You know that *conductors* of the electric fluid differ from each other in their conducting power.

C. Yes; the metals are the most perfect conductors, then charcoal, afterwards water and other fluids. This you taught us in our second conversation on electricity.

T. In voltaism we call the former *dry* and *perfect* conductors; these are the first class: the latter, or second class, *imperfect* conductors; and, in rendering the voltaic power sensible, the combination must consist of at least three conductors of the different classes.

J. Do you mean two of the first class, and one of the second?

T. When two of these bodies are of the first class, and one is of the second, the combination is said to be of the *first order*.

C. The large battery which you used yesterday was of the *first order* then, because there were two metals, viz. zinc and silver, and one fluid.

T. This is called a *simple voltaic pair;* the two metals touched each other in some points, and at other points they were connected by the fluid, which was of a different class.

J. Will you give us an example of the second order?

T. When a person drinks porter from a pewter mug, the moisture of his under lip, as I have already told you, is one

conductor of the second class, the porter is the other, and the metal is the third body, or conductor of the first class.

The discoloration of a silver spoon, in the act of eating eggs, is a voltaic operation. The fluid egg and the saliva are substances of the second class of conductors, and the silver of the first class.

C. Which are the most powerful voltaic combinations?

T. In all practical voltaic combinations, *zinc* is used for the positive metal, and is, with rare exceptions, always amalgamated; it is then unattacked by the exciting solutions while the battery is at rest; and when the battery is in action, it is consumed in exact proportion to the electricity produced. Gold, platinum, graphite or carbon, silver, copper, or iron, are used for the negative metal; and as far as the metals are concerned, platinum is employed in opposition with zinc to produce the best combination: gold is too expensive; carbon is nearly as good as platinum.

C. And I suppose that, having selected the metals that are most opposed to each other in their electro-chemical characters, the power of their combination varies with the nature of the solution used?

T. Yes; according as the difference between the chemical affinity of the solution for the respective metals is greater, the quantity of electricity produced is greater; and it is also greater in proportion as the solution is a better conductor of electricity. The actual force of the electric current, circulating in the conducting wires that are in connection with a voltaic battery, depends on many circumstances.

C. Can we understand these circumstances?

T. I will endeavour to explain them to you. The following is Professor Ohm's equation representing the force of a voltaic series:

$$F = \frac{n\,E}{n\,R + r}.$$

F represents the force; E, the electro-motive force of each cell, depending on the conditions I have just given you; R, the resistance opposed by each cell to the passage through it of the electric current, which is less according as it conducts better: by cell is here included the liquid and the metals; *r*, the resistance of the conducting wire, or circuit, whether part solid and part liquid, or all metal; *n*, the number of cells.

C. Then the more I increase the value of the numerator, or upper term of that fraction, the greater is the amount of force circulating?

T Yes; and if you could increase it to an unlimited extent without altering the denominator, you could have an unlimited supply of electricity. But, when the electro-motive force E is at its maximum by using the best solutions, you can do nothing further in that respect. You may now increase the number of cells *n*; but this also increases the number of resistances R, and so your denominator is increased, and the value of the fraction is kept down. If *r*, the resistance of the connecting wire, is very little, from using a short wire, not much advantage is gained by adding cells; but, if the wire is very long, cells are advantageously added. These laws are practically carried out in all applications of electricity.

C. Give us an illustration of batteries of a more powerful class.

T. Considerable attention has of late been paid to the subject, and much anxiety has been evinced to obtain a really good and constant voltaic combination; for, in the arrangements heretofore described, the power very soon fails. The late Professor Daniell, of King's College, devised a voltaic combination, which in practice has been very much approved of: he used two metals and two liquids. The metals are zinc and copper; the liquids are water containing sulphuric acid, and solution of sulphate of copper. The zinc is immersed in the former, and the copper in the latter. The two liquids are separated by tubes of porous earthenware, by animal membrane, canvass, paper, &c., according to the taste or convenience of the person using them.

C. What is gained by this arrangement?

T. The solution of copper becomes decomposed by the electric action then going on; and metallic copper is deposited upon the copper plate, so that a clear and perfect surface of metal is maintained; and the solution of zinc that is formed is preserved separate from the copper, and does not, therefore, interfere with the results.

J. And is this the most powerful combination?

T. No: the most powerful is the arrangement devised by Professor Grove. His metals are zinc and platinum, and his liquids, dilute sulphuric acid and strong nitric acid, kept apart by a cell of porous earthenware. The effects produced by only 100 of these are powerful in the extreme. The Chevalier Bunsen has used carbon instead of platinum.

C. When I have seen you busy with your electrotype experiments, I have often heard you asking for your "Smee;" what can that be?

T. It is a voltaic combination called after its inventor; but

he himself called it the *chemico-mechanical* battery, from its properties. Its metals are zinc and silver, coated with finely divided platinum; the liquid is dilute sulphuric acid. When this begins acting, a quantity of hydrogen gas is given off at the silver plate; and instead of partially adhering to the plate, and obstructing the action, as would be the case with a smooth plate, the minute particles of platinum cause the gas to ascend in constant streams, and so give place to the escape of fresh gas and the production of fresh action. I have myself, on this hint, used a similar battery, only instead of platinized silver I have used copper, with fine particles of copper thrown down upon it.

C. But where does this gas come from?

Fig. 4.

T. I will show you the experiment to which I referred in our last conversation. A B exhibits a glass tube filled with water, and having a cork at each end: A and B are two pieces of platinum wire, which are brought to within an inch or two of one another in the tube, and the other ends are carried to the battery, viz. A to what is called the positive end, and B to the negative end.

J. You have then positive and negative in voltaic electricity?

T. Yes, and if the circuit be interrupted, the process will not go on. But if all things be as I have just described, you will see a constant stream of bubbles of gas proceed from the wire B. This gas is found to be hydrogen, or inflammable air.

C. How is that ascertained?

T. By making arrangements to collect them, and the gas will immediately inflame on the approach of a light. The bubbles which proceed from the wire A are oxygen gas.

J. How is this experiment explained?

T. The water is decomposed, or divided into hydrogen and oxygen: the hydrogen is separated from the water by the wire connected with the negative extremity, while the oxygen is liberated at the positive end of the battery.

If I connect the positive end of the battery with the lower wire, and the negative with the upper, then the hydrogen proceeds from the upper wire, and the oxygen from the lower wire.

J. Why did you employ platinum wire?

T. Because I wished to avail myself of a property which platinum has, of not having any great affinity for oxygen. Unless I had done this, I could not have shown you the two gases; for, had I used copper, the oxygen, instead of making

its appearance, would have combined with the copper, for which it has a great affinity, and would have produced an oxide of copper.

C. Are there no means of collecting these gases separately?

T. Yes; instead of making use of the tube, let the extremities of the wires, which proceed from the battery, be immersed in water at the distance of an inch from each other; then suspend over each a glass vessel, inverted, and full of water, and the different kinds of gas will be found in the two glasses.

Fig. 5.

An arrangement of this kind properly mounted, and having the glass vessels duly graduated, is termed a voltameter, because it measures the quantity of electricity passing through it, by the quantity of gas evolved. The name was given by Dr. Faraday, who investigated this branch of the science very fully.

It is known that hydrogen gas reduces the oxides of metals, that is, restores them to their metallic state. If, therefore, the tube be filled with a solution of acetate of lead* in distilled water, and a communication be made with the battery, no gas is *perceived* to issue from the wire, which proceeds from the *negative* end of the battery, but in a few minutes beautiful metallic needles may be seen on the extremity of the wire.

J. Is this the lead separated from the fluid?

T. It is; and you perceive it is in a perfect metallic state, and very brilliant. Let the operation proceed, and these needles will assume the form of fern, or some other vegetable substance.

C. Can other metals be separated in like manner?

T. Yes: as, for instance, if you pass the voltaic current through a solution of sulphate of copper you release the copper; and by using a battery, the power of which is somewhat moderate, you may obtain the copper, in a compact malleable form. And if, in addition to this, you use a metal mould of any object, the released copper takes the form of this mould, and you obtain an *electrotype*.

C. And is electrotype so easy as this?

T. Much easier; get me a nail and a little piece of thin copper wire. Twist one end of the wire round the nail; warm the other end, and press it upon the edges of the seal that I will break off from the letter you have just received from your sister Emma; and I dare say we can manage that you shall

* Acetate of lead is a solution of lead in acetous acid.

answer the letter by to-night's post, and seal it with the same impression that she employed.

C. What; can we do this, and in so short a time? I shall be delighted; Emma will be so astonished; she will fancy that, by some means or other, we must have obtained her seal.

T. Moisten the surface of the seal with spirits of wine, while James runs down stairs to ask Mary for a little black-lead. Polish the surface with black-lead. You have now a voltaic pair ready, the metals being iron and black-lead. For liquids, take weak diluted sulphuric acid and solution of sulphate of copper. Put the sulphate of copper into a tumbler; sew a card into a kind of bag, and wax the edges that it may not leak; fill it with the acid water: place the nail in it, and bend the wire, so that the seal may hang over the side; place the whole in the tumbler of sulphate of copper, when the seal will become immersed in the solution. Leave it still for six or eight hours, when you will find a thick piece of copper has deposited on the seal; which is an accurate copy of the seal.

J. And is this the plan by which the many large electrotypes are obtained?

T. The principle is the same, but modified according to circumstances. When you were last at the Museum of Economic Geology, you saw the large casts of Alexander's triumph, which I prepared for that institution. They are two feet wide, by two or three long. This was my plan: a large strong flat wooden trough, containing upwards of 100 gallons of sulphate of copper, was prepared; a plaster-mould of the object was provided with a metallic surface, and well black-leaded. This was sunk in the trough, face upward, and was connected by a wire with the negative end of a voltaic battery. A large sheet of copper was suspended over this, and was connected with the positive end of the battery; the battery was kept in action for a few weeks, and the cast was then broken away.

J. But the battery must have had enormous power?

T. Not at all: it consisted of only two cells; the metals were zinc, and rough copper, each presenting a surface of about six square feet; the liquid was acid water.

C. I now see how electro-plating must be done: for if some solution of silver were used instead of copper, the deposit would be of silver, of course; and so with other metals.

T. Yes: and the whole art of electro-metallurgy, or working in metals by electricity, consists in making a good selection of solutions, and carefully adjusting the power of the battery to the work to be done.

J. What was the large sheet of copper for, in your great experiment?

T. Of course, in proportion as copper is released from the trough, and deposited upon the mould, the solution becomes weaker; but you remember I just now told you that, in cases of electro-chemical decomposition, the oxygen does not appear at the copper surface, but combines with the metal, and produces an oxide.

J. Oh! I see: and while copper is taken *out* of the solution at the mould, it is taken *in* at the copper surface, and so the strength of the solution is not diminished.

T. You are right; and this leads me to speak of electro-etching. You can readily imagine that if one half of the copper plate had been varnished over, that part would have been protected from the oxygen, and would not have dissolved. Now, by first covering the whole plate with varnish, and then tracing any design through to the copper, the oxygen would only attack the exposed parts, and so etch out a design. For the various details connected with Electrotype Manipulation, I must refer you to the printed manuals.

C. Is not the operation of the battery very powerful?

T. The spark from a voltaic battery acts with wonderful activity upon all inflammable bodies; and experiments made in a dark room, upon gunpowder, charcoal, metallic wire, and metallic leaves, &c. may be rendered very amusing.

J. Has not the voltaic battery been applied to the decomposition of certain substances, that were formerly supposed to be simple bodies?

T. Sir Humphrey Davy, by means of a very powerful battery, was enabled to decompose the alkalies, many of the earths; also the boracic, fluoric, and muriatic acids. His first experiments were on potash and soda, which, instead of being simple bodies, are found to consist of certain metallic substances and oxygen.— See "Dialogues on Chemistry."

C. Did he decompose these substances by placing them within the circuit of the voltaic fluid?

T. He did; in a manner very similar to what you have seen in the experiments with the apparatus. The alkalies, &c. were placed on the glass, and the two wires brought from the positive and negative ends of the battery.

J. Did the wires partake of the like properties with the two ends of the battery?

T. They did; one wire was positive, and the other negative. It was then found, after the action of the battery, that of the two

substances of which the alkali was composed, one uniformly went to the positive, and the other to the negative wire.

C. You said the alkali was discovered to consist of a *metal* and *oxygen;* which of these united with the positive, and which with the negative wire?

T. The oxygen was found at the end of the positive wire, and the metal at the negative end.

C. I notice that oxygen and hydrogen always appear in the same places. Is there a constant regularity in the appearance of other bodies?

T. If an electric current is passing through a solution, the rule is, that oxygen, chlorine, iodine, bromine, fluorine, cyanogen, and the acids are liberated where the current enters the solution; and that hydrogen, the metals, and the alkalies are liberated where the current leaves the solution: also, that, in mixed solutions, the elements are liberated according to a certain known order; as, for instance, hydrogen is released sooner than zinc, and zinc sooner than gold.

C. Do chemical qualities depend on electrical powers?

T. They are seen, as far as experiments have gone, to coincide with certain electrical states of bodies in general. Acids, as we have observed, go to the positive pole; alkalies, to the negative. Inflammable bodies go to the negative; and are all found to lose the peculiar properties and power of combination, by a change of their electrical states.

A remarkable application of electro-chemical decomposition occurs in certain forms of the electric telegraph; of which the most successful is Bain's chemical printing telegraph. Paper is dipped in a solution that is easily decomposed by voltaic electricity; and is made to move by clock-work in front of a point from which the telegraph current passes through the paper, in order to complete its journey; as it passes it decomposes the liquid, and makes a coloured mark. If it passes for a moment this mark is a dot; if for a little longer, the mark is a long dot or line. The alphabet is constructed from a combination of these dots. A is *one* dot and *one* line; B, *three* lines; C, *three* dots, and so on.

CONVERSATION IV.

Miscellaneous Experiments.

T. The discoveries of Galvani were made principally with *dead frogs*: from his experiments, and many others that have been made since his time, it appears that the nerves of *animals*

may be affected by smaller quantities of electricity than any other substances with which we are acquainted. Hence limbs of animals properly prepared have been much employed for ascertaining the presence of voltaic electricity.

C. What is the method of preparation?

T. I have been cautious in mentioning experiments on animals, lest they should lead you to trifle with their feelings: I must, however, to render the subject more complete, tell you what has been done.

The muscles, that is, the flesh, of a frog lately dead and skinned may be brought into action by means of very small quantities of common electricity.

If the leg of a frog recently dead be *prepared*, that is, separated from the rest of the body, having a small portion of the spine attached to it, and the nerves exposed, and so situated that a little electricity may pass through them, then the leg will be instantly affected with a kind of spasmodic contraction, sometimes so strong as to jump a considerable distance.

It is now known that similar effects may be produced in the limb thus *prepared*, by only making a communication between the nerves and the muscles by a conducting substance. Thus, in an animal recently dead, if a nerve be detached from the surrounding parts, and the coverings be removed from over the muscles which depend on that nerve, and if a piece of metal, as a wire, touch the nerve with one extremity, and the muscle with the other, the limb will be convulsed.

C. Is it necessary that the communication between the nerve and the muscle should be made with a conducting substance?

T. Yes, it is: for if sealing-wax, glass, &c. be used, instead of metals, no motion will be produced.

If part of a nerve of a *prepared* limb be wrapped up in a slip of tinfoil, or be laid on a piece of zinc, and a piece of silver be laid with one end upon the muscle, and with the other on the tin or zinc, the motion of the limb will be very violent.

Here are two wine-glasses, almost full of water, and so near each other, as barely not to touch. I put the *prepared* limb of the frog into one glass, and lay the nerve, which is wrapped up in tinfoil, over the edges of the two glasses, so that the tin may touch the water of the glass in which the limb is not. If I now form a communication between the water in the two glasses, by means of silver, as a pair of sugar-tongs, or put the fingers of one hand into the water of the glass that contains the leg, and hold the piece of silver in the other, so as to touch the coating of the nerves with it, the limb will be immediately excited, and

sometimes, when the experiment is well made, the leg will even jump out of the glass.

J. It is very surprising that such kind of motions should be produced in dead animals.

T. They may be excited also in living ones: if a live frog be placed on a plate of zinc, having a slip of tinfoil upon its back, and a communication be made between the zinc and tinfoil, by a piece of metal, as silver, the same kind of contraction will take place.

C. Can this experiment be made without injury to the animal?

T. Yes; and so may the following: I take a live flounder, and dry it with a cloth, and then put it on a pewter plate, or upon a large piece of tinfoil, and place a piece of silver on its back; I now make a communication between the metals with any conducting substance, and you see the contractions, and the fish's uneasiness. The fish may now be replaced in the water.

I place this leech on a crown piece, and then, in its endeavour to move away, let it touch a piece of zinc with its mouth, and you will see it instantly recoil, as if in great pain: the same thing may be done with a worm.

It is believed that all animals, whether small or great, may be affected in some such manner by voltaic electricity, though in different degrees.

M. Matteucci has added much to our knowledge of electro-physiology. You may remember that, in voltaic electricity, a certain chemical action always takes place, and this, by the soundest philosophers, is believed to be the cause of the electrical action; and it is shown that, in all cases of chemical action, there is a correspondent amount of electrical action, which by proper arrangement may be rendered manifest. Now, the muscles of animals are produced by certain chemical actions, by which the food enters into new combinations.

C. Yes, undoubtedly; but you do not surely mean to say that a certain amount of electricity is produced?

T. I do: and if pieces of flesh are properly arranged, the electricity may be obtained. On account of the great tenacity of life in frogs, it is best shown in these animals. Several frogs are killed; and the skin being removed from their legs, several legs from the knee upwards are collected, and placed in order one against the other, like so many zincs and coppers in an ordinary voltaic pile; and then, by applying proper apparatus, a current of electricity can be collected.

C. Well, this is curious; and have we currents of electricity in the same way?

T. Yes, indeed we have; but as human flesh is not so tena-

cious of life as frog's flesh, an opportunity does not often occur to test this. But unfortunately, or, perhaps, for his sake we should say fortunately, Matteucci received a violent kick from a horse, which laid bare the muscles of his leg: instead of at once allowing the surgeon to dress the wound, he experimented upon the bare flesh, and discovered that human muscle produced an electric effect.

C. And pray, sir, how did he test the presence of electricity?

T. By means of a *galvanoscopic frog*, that is to say, a frog's leg with a piece of the nerve hanging exposed; on allowing the nerve to touch the inside and the outside of the wound, the limb of the frog contracted violently. It is a rule, that if a current of electricity passes along a *part* of a nerve, the *whole* of the nerve is excited, and the member to which the nerve belongs is contracted.

C. I am afraid, then, that we shall never have an opportunity of seeing that the human body is a generator of electricity, if this is the mode of showing it.

T. The fact has been demonstrated in another form by M. Du Bois Raymond. He places the fore-finger of each hand into a vessel of water, the vessels being in connection with a delicate instrument, which will indicate the presence of very minute quantities of electricity, should such be produced. He then strongly contracts all the muscles of one of his arms, and the needle of the instrument immediately indicates the presence of a current moving from the hand to the shoulder of the arm that has been contracted. The current is extremely feeble, and is less with persons of small muscular power, and is less also with the left arm than with the right; the right arm, from use, being the more powerful. When the arm is at rest, there is a current in the direction from the shoulder to the hand.

J. Has he discovered any thing more respecting this electricity that we appear to generate within ourselves, and to carry about with us?

T. He has published a large book on the subject, of which an abridgment has been made by Dr. Bence Jones. He has concluded that the nerves and brain, as well as the muscles, are, during life, endowed with electro-motive powers; that from the surface along the length of the muscle, the positive electricity is derived, and from the surface across the muscle, negative electricity is derived; that every minute particle of muscle or nerve acts in like manner to the whole; that the electricity we collect by due contrivances, is a very minute portion of incomparably more intense currents circulating around the ultimate particles of the muscles and nerves; that this power lasts after

death, as long as the muscular or nervous excitability endures; that the electro-motive power is in proportion to the mechanical powers of the muscle; that the natural current of muscles undergoes a negative change during the act of contraction, but it is not clear whether it diminishes, vanishes, or changes in its direction. He has declared other facts, to which I need not now refer.

By the knowledge already obtained in this science, the following facts are readily explained.

Pure mercury retains its metallic splendour during a long time: but its amalgam with any other metal is soon tarnished or oxidated: the two metals and the moisture of the atmosphere constituting a voltaic circuit, in which one of the metals is acted upon, as you saw the copper wire by which the electricity entered an acid solution.

Ancient inscriptions engraved upon pure lead are preserved to this day, whereas some metals composed of lead and tin, of no great antiquity, are very much corroded, for the same reason.

Works of metal, whose parts are soldered together by the interposition of other metals, soon oxidate about the parts where the different metals are joined. And there are persons who profess to find out seams in brass and copper vessels by the tongue which the eye cannot discover; and they can, by this means, distinguish the base mixtures which abound in gold and silver trinkets.

When the copper sheeting of ships is fastened on by means of iron nails, those nails, but particularly the copper itself, are very quickly corroded about the place of contact.

A piece of zinc may be kept in water a long time, with scarcely any oxidation; but the oxidation takes place very soon if a piece of silver touch the zinc, while standing in the water.

If a cup made of zinc or tin be filled with water, and placed upon a silver waiter, and the tip of the tongue be applied to the water, it is found to be insipid; but if the cup be held in the hand, which is well moistened with water, and the tongue applied as before, an acid taste will be perceived.

C. Is that owing to the circuit being made complete by the wet hand?

T. It is. Another experiment of a similar kind is the following: If a tin basin be filled with soap-suds, lime-water, or a strong ley, and then the basin be held in both hands, moistened with pure water, while the tongue is applied to the fluid in the basin, an acid taste will be sensibly perceived, though the liquor is *alkaline*.

From the voltaic experiments, of which I have thus presented you with a short account, it has been inferred:

1st. That voltaism has all the properties of ordinary electricity.

2d. That it is produced by the chemical action of bodies upon each other.

3d. That the oxidation of metals produces it in great quantities.

4th. That it is conducted by the same substances as common electricity.

5th. That the electricity produced by the torpedo and gymnotus, as well as that derived from living animal tissues generally, is identical with all other electricity.

CONVERSATION V.

ON ELECTRO-MAGNETISM.

T. At the end of the Conversations on Magnetism I promised to give some farther account of the recent discoveries tending to establish a connection between voltaic electricity and magnetism. I may now redeem that pledge.

Some years ago several philosophers attempted to influence the magnetic needle, by placing it in the open galvanic circuit; but no effect was perceptible. Mr. Oersted, secretary to the Royal Society of Copenhagen, however, repeated the experiment when the galvanic circle was complete; and immediately found that the magnetic needle, when placed near, was moved from its position.

J. And this is electro-magnetism?

T. And the general expression for the effects, is that an electric current will make a magnetic needle place itself at right angles to the said current; and a magnet will make an electric current rest at right angles.

C. And will not ordinary electricity produce a similar effect?

T. Yes; if you so modify it as that it shall take the current form, which can be managed by proper contrivance; always bearing in mind that a current or completion of the electric circuit is necessary.

C. Of course the direction in which the needle moves must be regulated according to fixed laws?

T. Yes: place this compass-needle on the table before you so that the north end of the needle shall point toward you; and if you then imagine an electric current flowing down you, from the head to the feet, the north end of the needle would move toward the right. By this simple rule you may always determine the

direction a needle would take under all circumstances. If, for instance, it had been a south end at which you were looking, it would have moved to the left; if the current had been flowing from your feet upward, and the north end had been before you, it would have moved to the left. As the needle and current are nearer to each other, the action is more energetic; as it also is in proportion as the current is greater.

J. You said that a magnet would move a current?

T. Yes: if you imagine a magnet fixed with the north end toward the current, and the current were descending, the action of the magnet would be to move the current to the left.

C. I suppose if a *descending* current acted on the north end, at the same time an *ascending* current acted on the south end, the effect would be proportionately increased.

T. Yes; and if you bend a piece of wire into an oblong quadrangle, and suspend the needle within this wire, you form an arrangement, in which the opposite ends of the needle are simultaneously acted upon by different parts of the same current moving in relatively different directions, and the effect is increased. This instrument is the nucleus of the galvanometer. The *galvanometer* consists of several convolutions of copper wire covered with silk or cotton, with a compass-needle suspended within; it is furnished with a circular card, divided into degrees; and the number of degrees to which the needle is deflected bears some relation to the power in motion. The galvanometer is variously arranged, according to the force and quantity of the current to be measured; sometimes being made of a short piece of very stout wire, and at other times of an immense quantity of very fine wire.

While describing the galvanometer, I must tell you of one of its applications that is most marvellous, namely, the *Electric Telegraph.* You are aware that electricity travels at an enormous velocity, so that to pass over a few hundred miles occupies literally no time at all. A galvanometer properly mounted is placed, for instance, at Dover, and another at London, and a current of electricity is sent along them both at the same time by means of wires properly erected between the places; and thus whatever deflection is produced on one is produced on the other. By certain adjustments, an ascending or a descending current may be sent at pleasure through these galvanometers, and thus a left-hand or right-hand movement of the needle may be obtained. By previously arranging that a certain motion or motions one way or the other shall represent the respective letters of the alphabet, correspondence is easily managed. For instance, two deflections to the left represent A; three, B;

four, C; one to the right and one to the left, D; one to the right and two to the left, E; and so on. Instruments of this kind, with various modifications, the invention of Messrs. Cooke and Wheatstone, are being extensively adopted on the different railways in England and on the Continent. So wonderfully rapid has been the progress of the electric telegraph, that a complete army of inventors have followed on each other's steps, and have wrested from electrical science almost every form in which the force can be made available. Many of these inventions are beautifully ingenious, but not practical; many are modifications or amplifications of previous contrivances. The whole of the civilised globe is rapidly becoming interlaced with telegraph wires; and by one of those most extraordinary coincidences, *gutta percha* was discovered at the very time when telegraph engineers were crying out for something to help them over the difficulties that beset them in their endeavours to obtain perfect insulation under all circumstances. This was soon followed by propositions, most successfully carried out, of crossing rivers and harbours, and finally the British Channel, with wire covered with this valuable insulating substance, and further protected from damage by hempen and wire ropes. M. Siemens in Prussia, and Mr. C. V. Walker in England, were the first to use gutta percha wires; the latter were made at Streatham by Mr. Forster. On the Dover Railway alone there are nearly a hundred instruments distributed among the respective stations, which are in unceasing activity throughout the whole of the day, telegraphing the movement of every train, and conveying intelligence from place to place. So familiar, indeed, and so certain have they become, that a person in London holds communication with another in Dover as familiarly as if they were in the same room.

C. This is almost miraculous. I saw the instrument in use the last time I was at Tunbridge; I had left my carpet-bag at Dover, and in less than five minutes I learned that it was all safe, and was coming on by the next train.

T. I have already spoken of the mutual action of magnets on electric currents; I must now tell you that electric currents act upon each other; the rule being that similar currents attract, and dissimilar repel. The complicated actions arising from converging and diverging, from direct and circular, currents are detailed at large in treatises on electro-dynamics.

J. But you have not yet shown us how the continued motion is produced which I see in many pieces of apparatus at the Polytechnic and elsewhere.

T. You noticed that a descending current made the north end of the needle move to the right; at the same time it was acting on the south end, although farther removed, and caused it to move to the left. When these two forces were in equilibrio, the needle came to rest; but if there had been no south end to act upon, or the force of the current were lost before it could act upon the south end, the north end would continue going to the right, and a constant motion would be the result. Imagine yourself standing on the surface of a circular pond of water, with an electric current descending and passing out of your feet, and diffusing itself in the water; then imagine a magnet floated vertically in the water by a wooden float, so that its north end is above the water. The tendency of this magnet would be to move to the right; and if it were properly guided, you would find it continue to rotate as long as the current passed.

C. But why does not the action of the current on the south pole counteract this motion?

T. Because the current exists only above the surface. On the surface, it is diffused and comparatively lost, and the south end is too low in the water to feel the influence of the current. And now if you examine all these arrangements, you will find that the current is made to act on one pole only of the magnet, or one pole only is made to act on the current. If you keep this one idea in mind, and divest yourself of all complication of ideas, you will readily be able to analyse all these apparently complex pieces of apparatus, and will understand the real principle far more readily than you would were I to harass you with a description of some of the many arrangements. I ought to tell you that Faraday was the first to produce a magnetic rotation.

C. But I have seen a little piece of rotating apparatus, which I have heard you call your Ritchie, that does not depend on this; for I have seen both poles active.

T. True; this depends on another property of electric currents. If an electric current passes round a piece of iron, the iron becomes a magnet for the time being. Now a wooden dish, divided into two cells by a partition, is placed between the poles of a horse-shoe magnet; a little piece of soft iron, coated with copper wire, is balanced on a pivot over this dish, and the two ends of the wire dip into the respective cells of mercury, which are connected with the respective ends of the battery. When the current passes, the two ends of the bit of soft iron become magnetic poles, and move in obedience to the attractive power of the magnet; but the momentum they acquire carries

the ends of the wire across the partition, and as they change cells, the direction of the current is altered, and the poles change; so that, instead of remaining at what would have been its place of rest, the piece of iron, which, by the by, is termed an electro-magnet, is carried onward, and so we have a continued rotation.

C. Could not this power be employed for practical purposes?

T. It has been applied on a small scale; but no arrangement has yet been devised, which is sufficiently sure and powerful, and at the same time economical, as to permit of its being introduced in the arts.

While speaking of electro-magnets, I should tell you that this is a mode in which magnetism is most powerfully developed. By means of electric currents passing round iron, there is scarcely any limit to the magnetic power. I have seen an electro-magnet constructed at Woolwich, under the direction of Dr. Faraday, that sustained several sets of fire-irons with great facility. There is an electro-magnet also that sustains a room full of people.

C. Can you tell us any uses to which the electro-magnet is applied?

T. I might tell you of several. Let me, however, refer to the telegraph which I just mentioned. You may remember that the signals are given by galvanometer-needles; now it would not be a very sure means of gaining attention, if the clerk were expected to keep his eye on the needles until he saw himself called. In this case the ear is the best attendant: a bell rings, for which purpose an electro-magnet is applied in the following manner. A clock-work movement is constructed, which sets in action the clapper of a bell; the movement is held back by a small detent, affixed to the keeper of an electro-magnet. When the keeper is attracted to the magnet the detent is set at liberty: so that the only contrivance necessary is to provide a means of conveying an electric current along a wire wound round the electro-magnet.

Many electric telegraphs depend for their action on the electro-magnet alone. Of this kind, Morse's American printing telegraph is one remarkable example; and Breguet's telegraph, used by the French government, is another. Current after current is sent along the wires of Morse's instrument; by touching a key, an instantaneous contact produces a dot, and, if held on a little, a line; for the keeper of the magnet carries a point, which presses upon a slip of paper that moves on. The alphabet is made up out of the combination of dots and

lines; *one* dot and *one* line is A; *one* line and *three* dots, B *three* dots, C; *one* line and *two* dots, D.

In Breguet's telegraph, the keeper of the electro-magn carries an escapement, which liberates a tooth of a scape-whe for every movement; on the same axis with the wheel is th index of the telegraph. The apparatus is so constructed, th the index assumes eight different positions in its circle. Ther are two needles, and the letters depend on the relative positio of the two:—the left needle vertical downward, B; vertic upward, F: the right needle vertical downward, N; vertic upward, I.

The electro-magnet has been successfully applied by Mr Shepherd to maintaining a pendulum in motion, and to com municating motion to a train of wheels; and thus he has pro duced the electric clock, which sends automatically every hou a time-signal to distant places, from the Royal Observatory a Greenwich; and which communicates motion simultaneousl to many clocks in different parts of the Observatory.

The pendulum hangs independently of the wheels and work of the clock. At each vibration to the right, it touches a ligh spring, and so enables an electric current to circulate around piece of iron and magnetize it. It then attracts a piece o iron, the motion of which raises a weight; the pendulum, o vibrating to the left, releases the weight, which falls, and i falling gives the pendulum a slight tap. This feeble tap a each alternate second keeps the pendulum in constant motion.

C. But how can we tell what a clock it is from a mere pen dulum?

T. Besides the work above mentioned, other springs are a hand, which get touched at each vibration; and thus electri currents are sent into electro-magnets, placed beneath mag netized steel bars. The bars are attracted alternately in eithe direction, and communicate motion to the wheels.

C. And how are time-signals sent?

T. The clock-wheels carry certain pins, which are so arranged that, at the end of every hour, they press some springs together, and so cause an electric current to flow along a wire previously prepared for it. Twenty-one times out of the twenty-four, it is allowed to pass on to the Electric Telegraph Company's wires; but at 12 at noon, 3 P.M., and 4 P.M., the large clock at the London Station of the South-Eastern Railway breaks this connection, and joins the time-wire to the South-Eastern Company's wires, and the signal goes to Dover or to Rochester as the case may be.

At 1 P.M., the Greenwich clock sends the current to an

electro-magnet, which attracts a piece of iron, and so draws the trigger, and causes the Great Ball to fall. The trigger also makes contact with another voltaic battery, and sends a current to an electro-magnet in the Strand which causes the ball to fall there; and this ball in falling sets a regulator-clock going, which is regulated so as to be a second or two too fast by one o'clock each day. A little catch stops this clock every day when itself indicates one o'clock, and it is every day set free when true one o'clock is, as I have said, signalled from Greenwich.

This regulating clock makes a certain contact at the last second of every minute, which causes an electric current to actuate an electro-magnet, and liberate the wheel of the illuminated clock that stands in the centre of the road-way. The wheel passes on one notch, and shows time minute by minute.

J. You said a great deal about induction when you were describing ordinary electricity; is there any induction in galvanic electricity?

T. Yes; if a current is sent along one wire, it induces a current in another wire placed near it; and this secondary current, as it is termed, is frequently employed in cases where the primary current would not be convenient. For instance, it provides us with a means of obtaining very powerful shocks. This apparatus is termed the electro-magnetic coil. A coil of thick, covered copper wire is wound round a reel; and outside this a much greater length of thin wire is wound. If the ends of the thin wire are placed in separate basins of water, and the hands be immersed in this water, a very violent shock will be felt every time the battery current is broken off from the other wire, after it has entered it. The more frequently the current is broken off, the more numerous are the shocks, and the more violent is the effect. The advantage of frequent breaking and making of contact has given rise to numerous pieces of apparatus, most of them self-active, by which this effect is brought about. The power of these coils is greatly increased by placing an iron rod, or still more, a bundle of iron wires, in the centre.

CONVERSATION VI.

MAGNETO-ELECTRICITY — THERMO-ELECTRICITY.

C. As James and I are about to leave you this week, we are both very anxious to learn anything further you can teach us relative to electricity and magnetism.

T. We have already seen that electricity produces magnetism. I will now tell you how magnetism will produce electricity.

Dr. Faraday took a ring of iron, and wound two separate lengths of covered wire over different parts; and he found that when a current was sent through one wire, a current occurred in the opposite direction. He conceived, and very truly, as he afterwards found, that the magnetism of the iron produced the current, just as the current in the other wire produced the magnetism. To prove this, he took a coil of wire, and connected its ends with a galvanometer; he placed within the coil an iron rod; and as soon as this was magnetized a current was produced in the wire; it moved in a given direction at the act of making the magnet; it ceased during the existence of the magnetism, and occurred in the opposite direction when the magnets were removed.

He now took the iron bar away, and employed a cylindrical bar magnet: when this was introduced into the coil a current occurred in a given direction; while it remained there the current ceased, and on its withdrawal the current occurred in the reverse direction. If a wire cuts the magnetic curves, or the curves cut the wire, there is a tendency to the production of a current. If, instead of a wire, a plate of copper is used, the same general effect occurs, with this additional advantage, that a succession of currents, or rather one continuous current, may be obtained. The first practical carrying out of this idea was in Faraday's *magneto-electric machine*, which consisted of a disc of copper rotating with its edge between the poles of a powerful horseshoe magnet. The direction of the current was from the centre to the circumference, or from the circumference to the centre, according to the direction of the rotation; and the electricity is collected by means of wires applied, one to the edge, the other to the centre, of the disc.

C. Does this machine produce powerful effects.

T. No; but Saxton contrived a machine, in which coils of wire were rotated in front of a magnet; the ends were properly attached to connecting metals, so as to direct the currents, and violent shocks and brilliant sparks, with all the voltaic effects, may be obtained. For shocks a long coil of thin wire is used; for light, heat, and chemical decomposition, a shorter length of thin wire is employed. The magneto-electric machine is used for some forms of electric telegraph, and also for plating and gilding by electricity.

It is not necessary to have magnets to produce these effects, for they have all been produced, though in a less degree, by

the native magnetism of the earth. The machine in this case has been termed the *magneto-electro telluric machine.*

J. I have listened very patiently during our Conversations on Electricity to hear some notice of Armstrong's *hydro-electric machine*, which produces such brilliant effects at the Polytechnic.

T. I am glad you have reminded me of my omission; for, in the many things that I was anxious to describe to you, I had almost forgotten this. It consists of a high-pressure steam-boiler, furnished with a considerable number of escape-tubes the nozzles of which are lined with a small cylinder of box-wood; in front of the tube is a conductor furnished with points to de-electrise the steam as it escapes. It appears that as the steam escapes, a small portion of it is condensed into little particles of water: the uncondensed, as it escapes, rubs these water-particles against the box-wood, and the effect is exactly the same as rubbing the glass cylinder of the ordinary electrical machine against the cushion; a prodigious quantity of frictional electricity is produced; and the sparks collected from the boiler exceed in bulk and tension any that have been collected by other means.

J. You placed the word *thermo-electricity* at the head of this Conversation.

T. Yes; this is electricity produced by the motion of heat among the particles of certain metals. Mr. Seebeck discovered that a bar of antimony, differently heated in opposite parts, gave a current if these parts were metallically connected. But if a piece of bismuth is soldered to a piece of antimony, and heat be applied, the effect is very marked. Such an arrangement is termed a thermo-electric pair: several of these pairs combined is termed a thermo-electric pile.

C. Will these piles give shocks and sparks?

T. No, not directly; they will, by the intervention of a coil of copper riband. But they constitute the most delicate indicators of small quantities of heat that are known: some measure nearly to the hundredth part of a degree. If a pile is exposed to radiation from the human body, though at several yards distance, the heat affects it: an insect resting on it will also be indicated. And lately it has been employed successfully in proving that the moon possesses heat. Delicate thermo-pairs have been used to obtain the temperature of the human body, by being thrust into the arm. The temperature of plants and flowers has been measured. And to conclude with a sort of anti-climax to the many heat-producing effects of electricity, the thermo-electric apparatus has been employed to prove a case in which electricity produces cold: as when a very feeble

current passes the junction of bismuth and antimony. And now, my dear boys, I must bid you farewell. You must not leave me under the idea that you are well acquainted with physical science. All we have done is just to take a peep here and a glance there. We have trodden over the first parts of several branches of physics; we have looked at the leading features; and I trust you have seen and heard enough to induce you to make yourselves better acquainted with these subjects. I have felt more than ordinary interest in talking with you, because I could see in you a laudable desire to learn.

C. We are both very much indebted to you for your kindness, and very greatly regret that the arrangements which papa has made for us will not permit of our renewing these agreeable meetings.

J. For my part, sir, I can never be sufficiently grateful to you for the pains you have taken in instructing us.

GLOSSARY AND INDEX.

THE END.

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